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Impact of Cattle Feedlot Wastes on Surface Water Quality in Alberta

Alberta
ENVIRONMENTAL CENTRE

IMPACT OF CATTLE FEEDLOT WASTES
ON SURFACE WATER QUALITY IN ALBERTA

MICROBIOLOGICAL AND CHEMICAL
SURFACE WATER QUALITY

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EXECUTIVE SUMMARY

Livestock production is one of the major agricultural industries in the province of Alberta. In recent years intensive livestock operations have increased both in number and size in the province. This has been caused by an increasing demand for meat, poultry, and dairy products, and is also the result of changes in the economics of livestock management and production. This concentration of the livestock industry has coincided with rising public concern about the potential pollution of our environment and the effects of concentrating animal manure in localized areas.

Little specific information is available, however, on the nature and extent of potential surface-water pollution and associated public health problems from non-point sources such as feedlot wastes and runoff. Specifically, there is an apparent lack of data on the types and levels of microorganisms in bodies of water receiving cattle feedlot wastes and associated runoff, as well as on the microbiological relationships and interactions with certain physical and chemical parameters. Therefore, to provide the required information, a multi year study of the impact of cattle feedlot wastes and associated runoff on the quality of adjacent surface-waters in Alberta was initiated in the Spring of 1982 by the Microbiology Branch, Alberta Environmental Centre (AEC), Vegreville, Alberta. This was an interdisciplinary and interdepartmental project involving the participation of the Water Analysis and Research Branch, Chemistry Division, and the Biometrics Section, Animal Sciences Division, AEC; the Engineering Services Branch, Alberta Agriculture, Red Deer; and the Water Quality Branch, Alberta Environment, Lethbridge.

The objectives of the study were: (i) to study and determine the levels of microbiological, physical and chemical parameters in receiving surface waters at selected cattle feedlots in Alberta; (ii) to generate information on the nature and degree of impact of cattle feedlot wastes and associated runoff on the quality of adjacent surface waters; and (iii) to provide information on the fate of microbial parameters during their downstream transport in receiving surface waters adjacent to the feedlot.

Four cattle feedlots were selected as the study sites according to a set of criteria designed to optimize the results. Three of the feedlots (Palmer Ranch, Waterton; Prime Feeders Ltd., Fort Macleod, and Wes Yanke Ranch, Medicine Hat) were situated in southern Alberta. The fourth feedlot (Adams Ranch Ltd., Czar) was located in east-central Alberta.

Sampling stations were established at strategic locations in receiving waters, including the pre-impact (upstream of feedlot), impact (feedlot runoff point), influence (downstream of feedlot) and post-impact (further downstream) zones. The microbiological parameters that were determined were: total coliforms (TC); fecal coliforms (FC); fecal streptococci (FS); aerobic heterotrophs (20°C and 35°C); anaerobic heterotrophs; and total fungi. About 40 standard surface water quality physical and chemical parameters were also measured.

All microbiological data were statistically analyzed for significant differences for each survey, as well as to determine seasonal variations. In addition, physical and chemical data were statistically analyzed to ascertain their relationships with microbiological parameters, and for developing prediction equations that describe the fate of microorganisms during downstream transport.

Twenty-one surveys were conducted consisting of seven spring-runoff, five storm-event and nine dry-weather surveys. Local weather conditions influenced the number and types of surveys conducted at each feedlot.

The potential impact of runoff on surface water quality was found to be variable according to the feedlot site. At Palmer Ranch, for example, microbial densities were generally very low. Variable impacts on selected microbial parameters in receiving waters were observed, however. The most striking impact was seen during the storm-event survey when levels of fecal coliforms were about three times higher than the maximum recommended level (200 per 100 mL) for recreational waters*. Levels of chemical and physical parameters were generally low, but total Kjeldahl nitrogen and specific conductance values were elevated at the impact station during most surveys. The potential (adverse) impact of runoff from Palmer feedlot site was probably minimized by the large volumes of water and the fast-flowing nature of the Waterton River.

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* Alberta Surface Water Quality Objectives, 1977, (2); and Guidelines for Canadian Recreational Water Quality, 1983, (6).

Microbial levels were also low at Prime Feeders Ltd., but were generally higher than those observed at Palmer Ranch. Some impacts on levels of selected bacterial parameters were seen during spring-runoff surveys, but not readily demonstrated during storm-event surveys since densities were strikingly elevated at the pre-impact station (upstream of the feedlot) as well. There was no evidence of impact on physical or chemical parameters, although a slight input of total Kjeldahl nitrogen from the feedlot was indicated.

A similar picture was observed at Wes Yanke Ranch, although microbial densities were generally higher and more variable than those at Palmer Ranch. This was especially true of pollution-indicator bacteria (TC, FC, FS) which ranged from low to very high during spring-runoff and storm-event/dry-weather surveys, respectively. During the storm-event survey, densities of TC and FC were approximately two to nine times higher than the maximum recommended levels (1000 and 200 per 100 mL, respectively) for recreational waters (2, 6) at all sampling-stations. Thus, any direct impact from feedlot runoff was difficult to discern. No impacts on physical or chemical parameters were readily detected during any surveys at this feedlot.

The highest levels of all microbial and selected nutrient parameters were found at Adams Ranch Ltd., which reflected the eutrophic nature of the receiving waters at that feedlot.

The impact of runoff on all microbial and selected physical and chemical parameters in the slough adjacent to the feedlot was highly significant during most surveys. The water in the Ribstone Creek (downstream from the feedlot) was not adversely affected, however. This was caused by the limited flow of the creek that drained the slough.

Two statistical models were tested for their ability to predict the fate of microorganisms during downstream transport from the impact station at each feedlot. A distance-decay model, based solely on distances between sampling stations, did not satisfactorily account for the variations in microbial densities. However, a multiple-regression (multivariate) model, which incorporated physical and chemical parameters and environmental variables, was found to be useful and accounted for 73% to 93% of the variation in microbial densities. The most significant predictors of microbial densities were temperature, pH, non-filterable residues, filterable residues, turbidity, nitrite + nitrate nitrogen, specific conductance and distance. Therefore, these variables should be emphasized for future monitoring and impact assessment studies of this nature.

The results of this study showed that feedlot wastes and runoff contained varying types and levels of microorganisms, nutrients, metals and other contaminants, which could adversely impact the quality of receiving surface waters. The potential and extent of the impact was variable and markedly influenced by the feedlot type and associated waste management practices, as well as hydrological conditions and certain environmental factors. As an example, the concentrations of pollution-indicator bacteria were generally lowest during spring-runoff and highest during storm-event surveys at all feedlots. Some impact on selected microbial parameters was also indicated during dry-weather surveys. By contrast, no appreciable seasonal trends were observed with physical and chemical parameters.

The data also suggested that although minor to moderate water-quality problems exist at the monitored sites, the adverse impacts of feedlot discharges were generally short-lived, restricted and site-specific. Further, it was observed that microorganisms are not transported great distances downstream from upstream pollution sources because they are non-conservative and extremely sensitive indices, and their levels are influenced by a variety of complex environmental factors. It should be emphasized, however, that surface water immediately downstream of a feedlot are not recommended for body-contact recreational activities.

This study did not reveal any major and/or serious water-quality problems at the examined feedlots. Nonetheless, sound and practical waste management practices and runoff control measures should be applied continuously to minimize and prevent potential surface-water pollution problems. In this regard, some recommendations are suggested for improving livestock waste management practices. Also, the data and information from this study could be used as a general guide for the impact assessment of feedlot wastes, but SHOULD NOT BE EXTRAPOLATED to determine pollution-potential of other feedlots in Alberta. Certain suggestions are also made for any future studies of feedlot wastes and associated runoff on the quality of adjacent surface waters.

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1.0 INTRODUCTION

1.1 Background

In recent years, intensive livestock operations have increased both in number and size in the province of Alberta. This has been caused by a growing demand for meat and dairy products, and changes to the economics of livestock management and production. The development of confined livestock feeding has coincided with mounting public concern about the potential pollution of our environment caused by the concentration of manure and wastes in localized areas.

Management of the resulting livestock manure without contributing to air, soil and water pollution can be a major problem in the operation of modern feedlots. Conversely, it is also universally recognized that properly managed manure can be an important resource, especially if it is used to improve the physical conditions of soil, soil fertility and productivity. Clearly, the challenge is to establish a viable balance between optimum livestock production and environmental protection.

In recognizing the significance of the livestock industry, and because little specific information is available about cattle feedlot manure management and associated environmental effects in Alberta, the Microbiology Branch of the Alberta Environmental Centre (AEC) prepared a project proposal to conduct a study of the impact of cattle feedlot wastes on the quality of adjacent surface-waters with special emphasis on microbiological aspects. The proposal was submitted for evaluation to the AEC Technical Advisory Committee, which subsequently requested that additional information on the nature and the current significance of the problems of the confinement-feeding industry and associated manure management be provided for critical appraisal before initiating the project.

To furnish the required information, two approaches were selected. Firstly, a literature search was initiated to review post-1970 references dealing with various aspects of manure management at cattle feedlots and related environmental implications in North American studies. This resulted in a "Bibliography of Cattle Feedlot Manure Management" (12). Secondly, a workshop was organized (December 8-9, 1981) and held at the AEC to bring together government and university scientists, engineers and farm industry personnel to share their knowledge, experiences and concerns regarding cattle-feedlot operations in Alberta. The workshop, attended by about 60 people, was organized into three components: (i) presentations by the invited speakers; (ii) subject-oriented group discussions; and (iii) a general discussion session for summarizing group discussions. The workshop findings and highlights, including conclusions and recommendations for potential research areas, were summarized in "Cattle Feedlot Workshop Proceedings" (18).

The findings of both approaches indicated that although the water-quality impact of feedlot wastes had been extensively researched in the U.S., little specific information was available to define the problem as it currently exists in Alberta. It was noted that several studies were completed within the past two decades that attempted to assess the contributions of a few feedlots in Alberta to groundwater contamination or surface-water pollution. The results of these assessments were generally contradictory, however, and suggested that the potential for water pollution varies substantially among the feedlots (3, 9, 10, 12, 17, 18, 19, 20, 21, 22). For example, certain studies in southern Alberta indicated that phosphate and nitrate nitrogen levels in groundwater underneath feedlots were at acceptable levels year round and there was no evidence of nearby waters being polluted through lateral movement of water through the soil (21, 22). Another study in the same area reported that, although few nutrients move through a feedlot floor because of soil compaction, considerable amounts of nitrate-nitrogen can move downward in the soil adjacent to the feedlots and contact the groundwater in the drainage ways (10). In central Alberta it was found that nitrates did leach to a considerable depth in soils underneath feedlots and that the potential for groundwater infiltration existed (18).

Surface water studies that were done on the Oldman River and Willow Creek showed that pollution from nitrate-nitrogen, phosphorus, soluble salts and organic matter was not excessive but, however, generally exceeded the minimum criteria set by the Alberta Department of Health (20). It was recognized that carelessness by the agricultural industry could reverse the situation, however, and a later paper reported that Alberta Environment had documented at least three cases of feedlots contributing to surface-water pollution, including one location on the Oldman River (12).

Furthermore, it was stated that monitoring of rivers in Alberta as they passed through agricultural areas indicated that the industry does contribute to surface-water pollution (12). It should also be noted that in most of these studies, the water quality was assessed in terms of chemical parameters only. Related microbiological aspects and characterization were not considered.

A Detailed Operating Plan (DOP) for the Survey of Feedlot Wastes Project was prepared in April, 1982 at the request of the AEC Management Committee. The DOP contained a study plan and schedule of activities designed to generate data and information on the levels and fate of microorganisms and selected chemical and physical parameters in water bodies receiving cattle feedlot wastes in Alberta. Following the evaluation and approval of this plan, a Feedlot Waste Project Team was formed, and field and laboratory work was initiated on June 15, 1982.

1.2 Study Objectives

The objectives of the project were: (i) to study and determine the levels of microbiological, physical and chemical parameters in receiving surface waters at selected cattle feedlots in Alberta; (ii) to generate information on the nature and degree of impact of cattle feedlot wastes and associated runoff on the quality of adjacent surface waters; and (iii) to provide information on the fate of microbial parameters during their downstream transport in receiving surface waters adjacent to the feedlot.

1.3 Study Plan

In view of the stated objectives of the project, cattle feedlot study sites were sought where feedlot runoff (liquid effluents) drained, either directly or indirectly, to a receiving fluvial body of surface-water. In addition, one of two possible runoff drainage patterns could exist at the feedlot study sites: (i) runoff collecting into a common stream, which impinges as a point source on the receiving fluvial body of water (e.g. Figure 3.1); and (ii) runoff draining in a broad band (via several streams) and rendering a multipoint source impingement on the receiving fluvial body of water (e.g. Figure 3.2). It was also envisaged that study-site receiving waters must contain well-delineated pre-impact, impact, influence and post-impact zones (Figures 3.1-3.4). Further, to achieve these requirements, it was decided to select at least four feedlots through field visits. They would represent these runoff drainage patterns/distinct zones, and perhaps different density operations for the project and proposed surveys.

Ideally, four surveys for each feedlot were planned: (i) early spring and (ii) late spring to assess pulse loading during snow melt and spring runoff; (iii) summer-storm event to assess storm runoff contributions; and (iv) fall to determine dry-weather input.

With respect to sample collection, it was planned to establish five or more sampling-stations at strategic points in receiving water bodies including the pre-impact, impact, influence and post-impact zones. Further, only surface-water samples were to be collected from each station and analyzed for selected microbiological, physical and chemical parameters.

To assess impact on surface-water quality, it was planned to analyze water samples for seven microbiological parameters (Table 1.1) and approximately 40 physical and chemical parameters (Table 1.1), which are considered to be important for, and routinely used in, surface water quality assessment.

Table 1.1 List of microbiological, physical and chemical parameters

I Microbilogical

(1) Total Coliforms (TC)
(2) Fecal Coliforms (FC)
(3) Fecal Streptococci (FS)
(4) Aerobic Heterotrophs (HPC 20°C)
(5) Aerobic Heterotrophs (HPC 35°C)
(6) Anaerobic Heterotrophs (ANA) (Total Anaerobes)
(7) Total Fungi (RB/FUNGI) (Yeasts and Molds)

II Physical and Chemical

A Physical (Laboratory)

(1) pH (pH)
(2) Specific Conductance (S. COND)
(3) Filterable Residue (FR)
(4) Total Dissolved Solids (TDS)
(5) Nonfilterable Residue (NFR)

B Chemical (Laboratory)

a) Major Ions

(1) Total Alkalinity (T.ALK)
(2) Chloride (Cl)
(3) Sulphate (SO_4)
(4) Fluoride (F)
(5) Sodium (Na)
(6) Potassium (K)
(7) Calcium (Ca)
(8) Magnesium (Mg)

b) Nutrients

(1) Particulate Nitrogen (PART.N)
(2) Total Kjeldahl Nitrogen (TKN)
(3) Nitrite + Nitrate Nitrogen (NO_2 + NO_3)
(4) Nitrite Nitrogen (NO_2)
(5) Ammonia Nitrogen (NH_3)
(6) Total Phosphorus (TP)
(7) Orthophosphate (OP)
(8) Particulate Carbon (PART.C)
(9) Dissolve Organic Carbon (DOC)
(10) Chemical Oxygen Demand (COD)
(11) Biochemical Oxygen Demand (BOD)

c) Metals

(1) Aluminum (Al)
(2) Beryllium (Be)
(3) Cadmium (Cd)
(4) Cobalt (Co)
(5) Chromium (Cr)
(6) Copper (Cu)
(7) Manganese (Mn)
(8) Molybdenum (Mo)
(9) Nickel (Ni)
(10) Vandium (V)
(11) Zinc (Zn)
(12) Lead (Pb)
(13) Iron (Fe)

C Physical (Field)

(1) Temperature (TEMP)
(2) pH (pH)
(3) Turbidity (TURB)
(4) Dissolved Oxygen (DO_2)
(5) Hydrological Conditions (RID) e.g. Precipitation

2.0 FEEDLOTS

2.1 Field Visits and Site Description

Several candidate sites were proposed by Alberta Agriculture and Alberta Environment personnel. Field visits to all those sites were made by the Project Team to determine the effluent drainage (runoff) pattern, type of receiving water, ease of access to a watercourse for sampling, feasibility of sampling locations, presence of neighbouring influences (if any), and the overall feedlot layout and topography. In addition, feedlot operators were approached for their cooperation in the proposed study and to fill out a questionnaire to acquire pertinent information for the evaluation of their feedlots as potential study sites.

The detailed description of the 13 feedlots that were visited, including potential runoff drainage patterns to adjacent watercourses and the information acquired from questionnaires, is presented in an unpublished data appendix[1].

It was recognized during the search for suitable study sites that only a few feedlots in Alberta are ideally situated to meet the purpose of the study i.e. on or sufficiently close to fluvial bodies of receiving waters with high, consistent, year-round flow rates, and that most feedlots are located on small streams or creeks with slow and inconsistent flow rates. Also, it was known that dry spells during summer months would reduce or eliminate flow in the latter case, but adequate runoff for sampling would likely result during storm events. In addition many feedlots are not operated year-round and it is common practice for Alberta feedlot operators to pasture their cattle during summer months.

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[1] Appendix available upon written request.

Based on these findings, it was deemed necessary to:
(i) slightly modify one of the requirements of the study site to include less fluvial (flow rate <0.3 m^3/s) receiving waters so that a more typical feedlot runoff situation could be studied; and
(ii) increase the number of sampling-stations to >5, where appropriate, for more complete characterization of the feedlot runoff and affect on to the receiving bodies of water.

2.2 Site Selection Criteria

Information gathered from on-site (field) visits, questionnaires, field notes, slides and aerial photographs was reviewed, and feedlot sites were evaluated by the Project Team according to the following set of criteria:

(i) Geographical location

To provide optimum suitable information (slope drainage, etc.) for project objectives.

(ii) Fluvial body of receiving water

Small river/stream, continuous flow 0.3 m^3/s (>10 cfs).

(iii) Management practices

Preferably year-round operation, unpaved (earth and mud floor) type, sufficient animal density, runoff control/abatement measures.

(iv) Herd size

Sufficient to produce runoff, >100 animals.

(v) Public concern

In general this item considered perceptions about water quality, public health and aesthetics, and the intended use of the water (drinking, recreation, agriculture, aquatic life protection, etc.).

(vi) Feasibility of sampling

Preferably within a 6- to 8-h drive from AEC, single identifiable source, physical accessibility for sample collection, and access permission.

2.3 Feedlot Selection

Based on these criteria, each study site was scored in the following manner: 1 = feasible, 2 = less feasible, and 3 = not feasible. A summary of information evaluated for each of the 13 candidate feedlot sites is presented in the unpublished data appendix.

Of the 13 feedlot sites, six were initally ranked as feasible study sites (Table 2.1). Subsequently, the following four feedlots were selected as the final study sites: (i) Palmer Ranch, Waterton; (ii) Prime Feeders Ltd., Fort Macleod; (iii) Wes Yanke Ranch, Medicine Hat; and (iv) Adams Ranch Ltd., Czar.

For the purpose of this study, sampling stations at each of the four feedlots were designated as: pre-impact (upstream of feedlot); impact (feedlot runoff point); influence (downstream of feedlot); and post-impact (further downstream) as summarized in Table 2.2.

Table 2.1. List of six Alberta feedlots selected as feasible study sites

FEEDLOT/LOCATION (DRAINAGE BASIN)	RECEIVING WATERS/DISCHARGE RATES (m^3/s)[1]	REMARKS
(1) Palmer Ranch, Waterton (Oldman River)	Local stream, (no data) flowing into Waterton R. (Max. = 153, Min. = 2.5)	Length of driving time (10 to 12 h) may necessitate transport of samples by air and assistance of Alberta Environment, Lethbridge Lab.
(2) Prime Feeders Ltd., Fort Macleod (Oldman River)	Willow Cr. (Max. = 59.2, Min. = 0.055B[2])	Feedlot has been extensively studied by other agencies, however, no microbiological data are available.
(3) Copethorne Ranch, Cochrane (Bow River)	Jumping Pond Cr., (Max. = 59.2, Min. = 0.055B[2])	Cattle are pastured during summer months, not fed in confinement.
(4) Bonnett Farms, Ponoka (Battle River)	Local Cr. (no data) Flowing into Battle R. (Max. = 63.7, Min. = 0.36B[2])	Aerial photos, etc. needed to determine exact drainage course. Also, permission of owners for sampling would be difficult to obtain.
(5) Adams Ranch Ltd., Czar (Battle River)	Local stream, (no data) Flowing into Ribstone Cr. (Max. = 0.075, Min. = 0B[2])	Flow rate may be inconsistent during summer months, but sufficient flow would likely occur during storm events.
(6) Wes Yanke Ranch, Medicine Hat (S. Saskatchewan River)	Tributary, (no data) Flowing into Ross Cr.	Further flow-rate data to be obtained. Length of driving time (7 h) and road conditions (mostly secondary) may necessitate transport of samples by air.

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[1] 1981 figures from Surface Water Data for Alberta, Environment Canada, EN-36/403, 1981.

[2] B = ice conditions.

Table 2.2. Sample station designation

	STATION DESCRIPTION/NUMBER			
FEEDLOT	PRE-IMPACT (UPSTREAM)	IMPACT (FEEDLOT)	INFLUENCE (DOWNSTREAM)	POST-IMPACT (DOWNSTREAM)
Palmer Ranch, Waterton	1 & 2	3	4	5 & 6
Prime Feeders Ltd., Fort Macleod	1	2 & 3	4	5 & 6
Wes Yanke Ranch, Medicine Hat	1	2 & 3	4	5
Adams Ranch, Czar	1 & 5	2	3 & 4	6

3.0 MATERIALS AND METHODS

3.1 Field Procedures

During the study period (1983-1985), 21 surveys were conducted at the four feedlot sites under various hydrological conditions to examine and determine the impact of feedlot operations on the quality of adjacent receiving surface waters. As the results of year-round dry-weather conditions, particularly during 1983 and 1984 in the southern part of the province, not all types of surveys were conducted at all feedlots each year.

Sampling at the southern feedlots (Palmer Ranch, Waterton; Prime Feeders Ltd., Fort Macleod; and Wes Yanke Ranch, Medicine Hat) was carried out by Alberta Environment personnel located in Lethbridge. During these surveys, both microbiological and chemical samples were collected at the same time, stored on ice in insulated cooler chests during the collection period, and then shipped by air cargo to the AEC laboratory at Vegreville, Alberta. Samples from Adams Ranch Ltd., Czar, were collected by AEC personnel and tranported on ice in insulated cooler chests to the AEC laboratory.

3.1.1 Sampling Stations

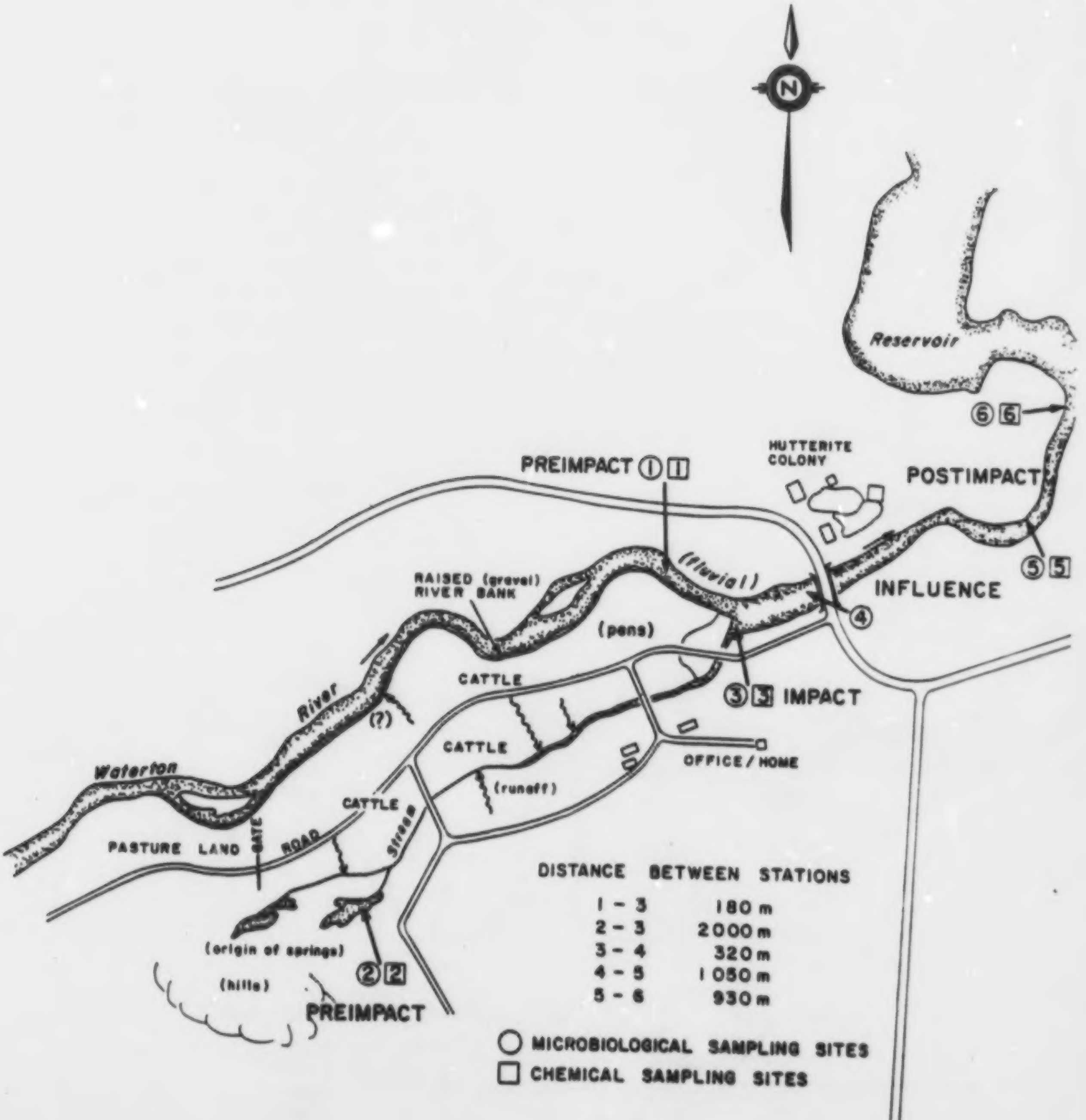
The locations of sampling stations for each feedlot are depicted in Figures 3.1 to 3.4. Microbiological stations (numbers in circles) were established at pre-impact (upstream of feedlot), impact (feedlot runoff point), influence (downstream of feedlot) and post-impact (further downstream) zones. Chemical sampling-stations (numbers in squares) were established at pre-impact, impact and post-impact zones only. The distances between all sampling stations were measured and recorded (Figures 3.1-3.4).

3.1.2 Sampling Procedures

Surface water samples (grab samples) were collected at a depth of 0.2 to 0.5 m with the aid of a sampling pole constructed from an aluminum rod (3-m long) and a chain clamp to which sampling bottles were attached. Triplicate samples for microbiological analyses were collected in a trianglar pattern 1.5 to 3.0 m apart at each station using sterile, wide-mouthed, one-litre Nalgene® bottles. A set of six samples for chemical analyses was collected using appropriate containers at one location at each station. Samples were then preserved and stored according to the requirements for the parameters, as outlined in the AEC Methods Manual for Chemical Analysis of Water and Wastes (2). Preservatives were added, where needed (Table 3.1), immediately after sample collection. All microbiological and chemical samples were placed on ice in insulated cooler chests and transported (via air and/or refrigerated van) to the laboratory on the day of sampling. Upon arrival, sample sets (microbiological and chemical) were sorted, and then their identity was verified. Sample bottles were then checked for leakage, stored at 4°C, and analyzed within 24 h of collection.

FIGURE 3.1

PALMER RANCH, WATERTON, ALBERTA



DISTANCE BETWEEN STATIONS

1 - 3	180 m
2 - 3	2000 m
3 - 4	320 m
4 - 5	1 050 m
5 - 6	930 m

FIGURE 3.2

PRIME FEEDERS LTD., FORT MACLEOD, ALBERTA

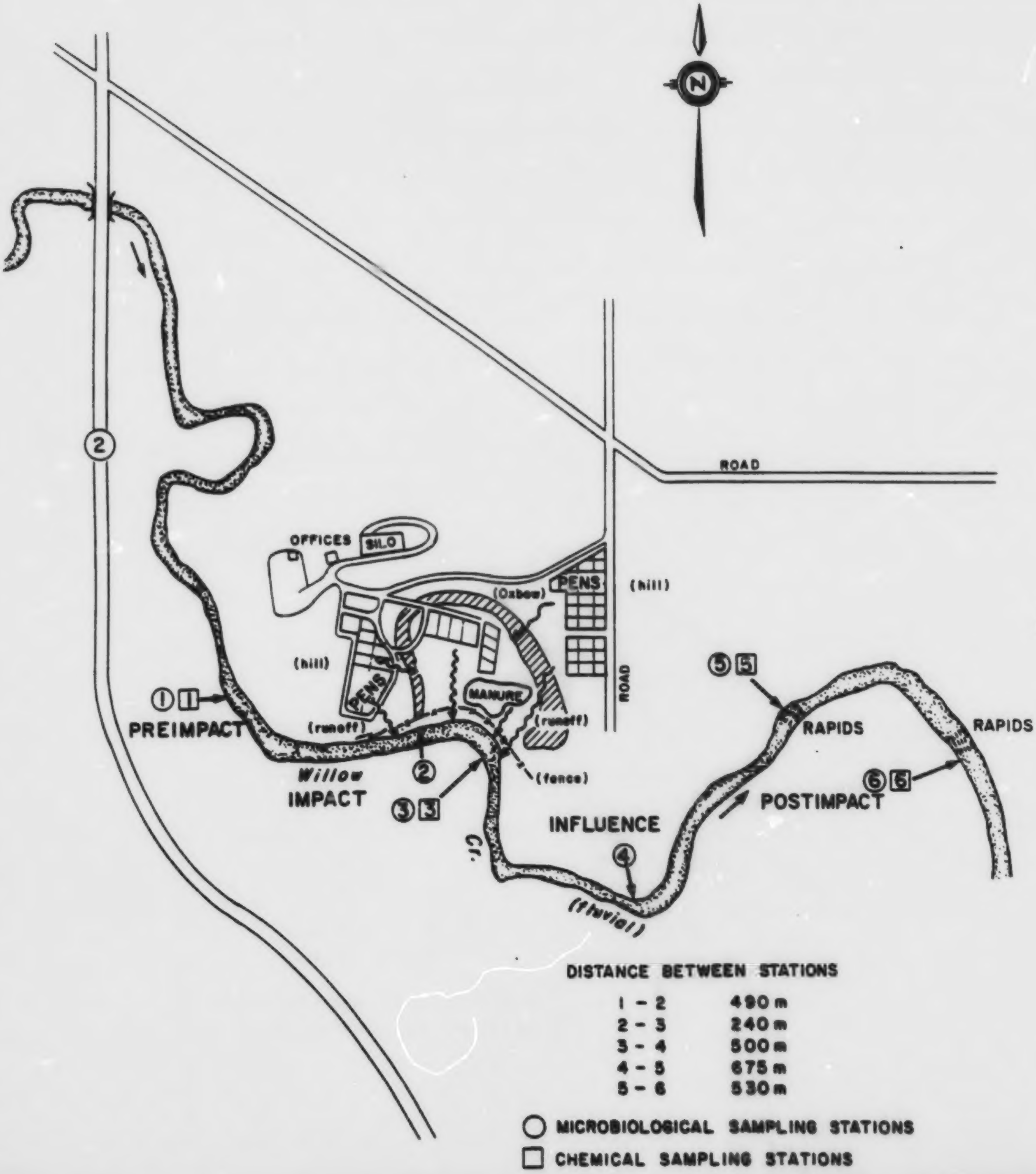


FIGURE 3.3

WES YANKE RANCH, MEDICINE HAT, ALBERTA

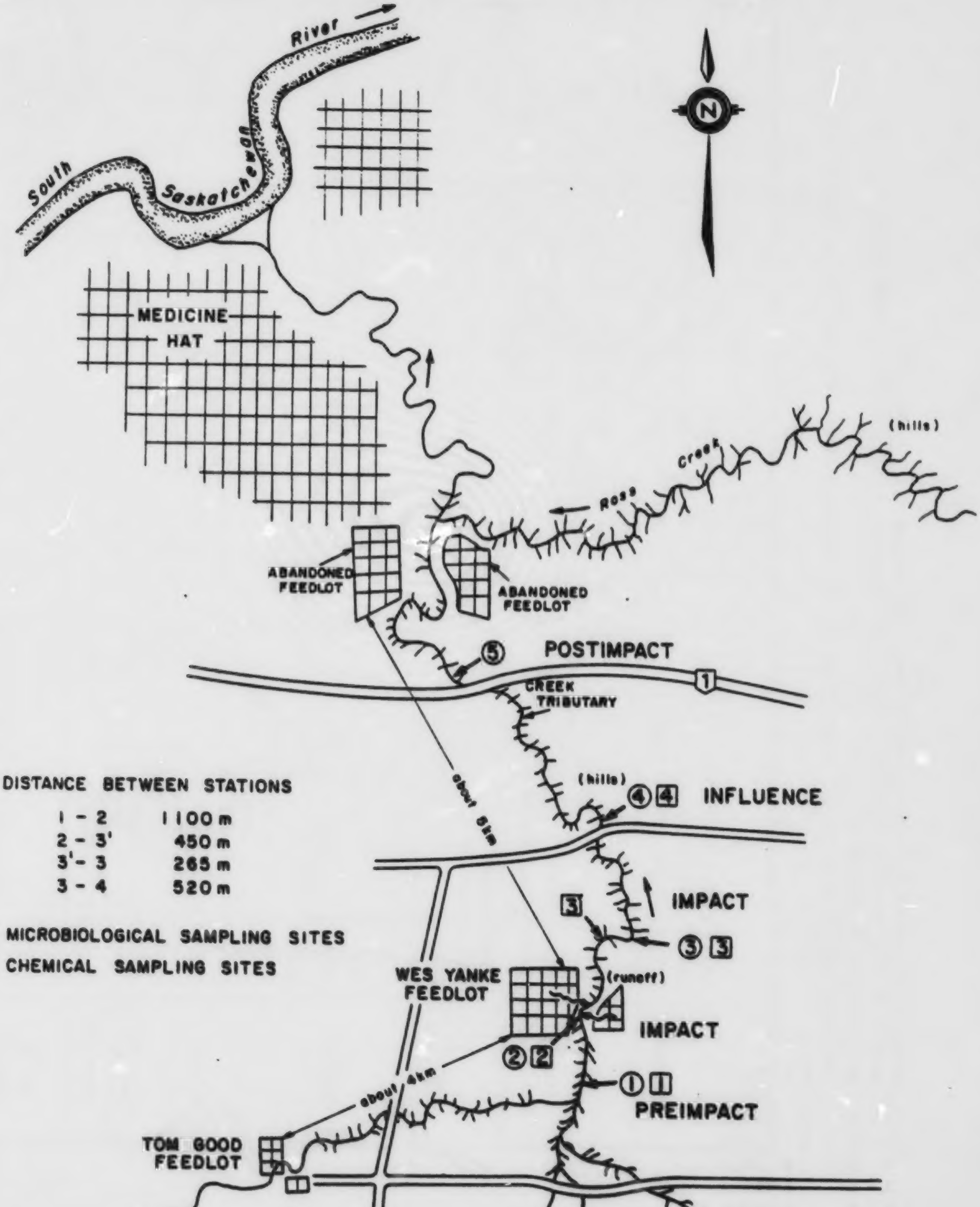
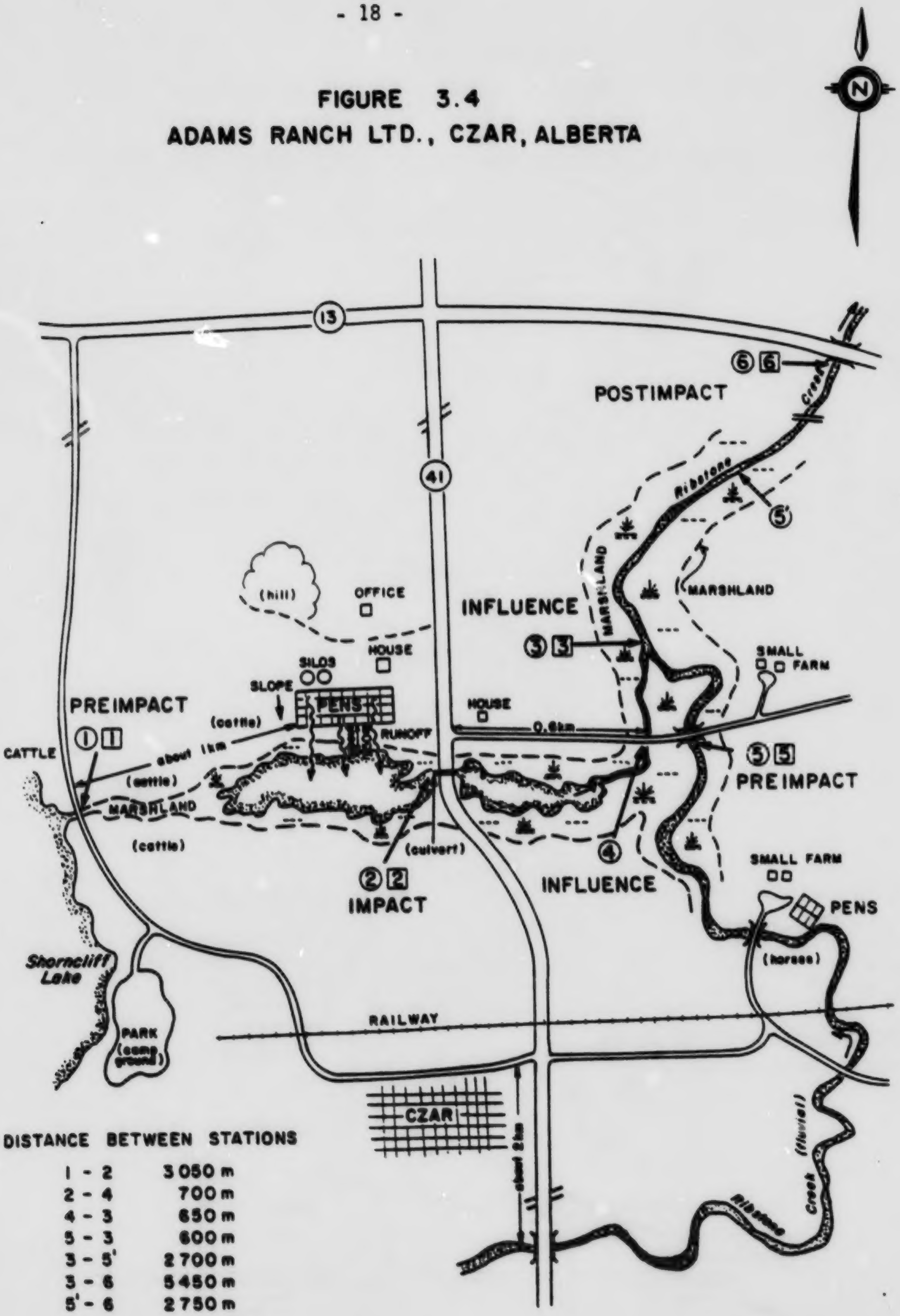


FIGURE 3.4
ADAMS RANCH LTD., CZAR, ALBERTA



DISTANCE BETWEEN STATIONS

1 - 2	3050 m
2 - 4	700 m
4 - 3	650 m
5 - 3	600 m
3 - 5'	2700 m
3 - 6	5450 m
5' - 6	2750 m

○ MICROBIOLOGICAL SAMPLING SITES
☐ CHEMICAL SAMPLING SITES

Table 3.1. Types of containers and preservatives used for the storage and preservation of chemical samples

Parameter Group	Tests Included in Parameter Group	Preservative	Container	Recommended Maximum Holding Time
Routine	pH Spec. Conductance Fluoride Calcium TDS (Calc.) Sulfate Magnesium Chloride Total Alkalinity Sodium Potassium	Cool to 4°C and transport to lab as soon as possible	500 mL polyethylene	7 days
Metals	Cadmium Manganese Aluminum Copper Chromium Beryllium Nickel Vanadium Lead Cobalt Molybdenum Zinc Iron	Blue Dot (5 mL 50% HNO_3)	500 mL polyethylene	3 months
General-1	BOD FR NFR	Cool to 4°C and transport to lab as soon as possible	2000 mL glass (with teflon liner)	6 hours
General-2	COD Total Kjeldhal Nitrogen Total Phosphorous Ammonia-Nitrogen	Brown Dot (2 mL 5% H_2SO_4)	125 mL polyethylene	7 days
Low Level Nutrients	Orthophosphate Nitrate-Nitrogen Nitrite-Nitrogen	Cool to 4°C and keep out of sunlight; transport to lab as soon as possible	125 mL polyethylene	24 hours
Carbons	DOC: Dissolved Organic Carbon Part C: Particulate Carbon Part N: Particulate Nitrogen	Cool to 4°C and keep out of sunlight; transport to lab as soon as possible	125 mL polyethylene	24 hours

Instructions:

1. Assure that sample bottle is dust-free. (Rinse sample container with sample several times before collecting aliquot for analysis).
2. Fill bottle within 90% of capacity.
3. Break off ampoule top and empty into filled sample bottle (CAUTION: PRESERVATIVES ARE STRONG ACIDS)
4. Avoid using an intermediate sampling container which could contaminate the sample.

3.1.3 Field Parameters

Measurements of the water temperature, pH, dissolved oxygen content and conductivity at each sampling station were made using a Hydrolab digital water quality instrument Model 4041 (Hydrolab Corporation, PO Box 50116, Austin, TX) or a YSI Model 58 dissolved oxygen meter (Yellow Springs Instrument Co., Yellow Springs, OH), Metrohm conductivity meter Model E567 and pH meter Model E488 (Sybron-Brinkmann Instruments, Inc., Rexdale, ON). Results of measuring these physical parameters, and information on prevailing hydrological conditions (i.e. weather, wind and amount of precipitation during each survey), were recorded on field data sheets. In addition, the amount of snow cover, vegetation and appearance of receiving water at each sampling station were also recorded on the field data sheets.

Flow rates and gauge heights (water depth) of major receiving waters, such as Waterton River (Palmer Ranch), Willow Creek (Prime Feeders Ltd.) and Ribstone Creek (Adams Ranch Ltd.), were obtained from the Water Quality Branch, Alberta Environment, Calgary, Alberta. In addition, measurement of the flow rates of minor receiving waters, such as the creek adjacent to Wes Yanke Ranch and the creek draining the slough at Adams Ranch Ltd. (culvert flow), was made by personnel of the Water Quality Branch, Alberta Environment at Lethbridge and Edmonton.

Records of daily precipitation at the weather station closest to each feedlot site were obtained, courtesy of the Atmospheric Earth Sciences Service, Environment Canada, Edmonton.

3.2 Laboratory Procedures

3.2.1 Microbiological Analyses

In general, membrane filter (MF) and heterotrophic plate count (HPC) procedures as outlined in APHA Standard Methods (5) were followed for the estimation of pollution-indicator bacteria and aerobic heterotrophs, respectively. Anaerobic heterotrophs and total fungi were determined using the spread-plate procedures outlined in the AEC Microbiological Methods Manual (3). For MF analyses, three or more appropriate volumes of each sample were analyzed in duplicate. Incubation of all MF plates was accomplished using plastic "Freezette®" containers (Bel-Art Products, s-Technilab Instruments, Inc., Pequammock, NJ) with a wet paper towel inside to provide an atmosphere of saturated humidity. For plate-count enumerations, four replicates of three appropriate dilutions were plated out for each sample.

All the employed media were obtained from Difco Laboratories, Detroit, MI., and membranes for MF analyses were obtained from Millipore Corporation, Bedford, MA.

The details of specific materials and procedures used for the determination of various microbial parameters are given below.

(a) Total Coliforms(TC)

Total coliform counts were performed on Millipore (HA)® membrane filters (47 mm diameter, 0.45 μ gridded filter membranes) applied to m-Endo (Difco) medium and incubated for 22 ±2 h at 35°C. The presence of typical colonies exhibiting a metallic sheen under a mixture of fluorescent and daylight lighting were counted and recorded in terms of total coliform per 100 mL of water sample.

(b) Fecal Coliforms (FC)

Fecal coliform counts were performed on Millipore (HC)* membrane filters, (47 mm diameter, pore size 0.7 μ white gridded filter membranes), applied to m-FC agar (Difco) and incubated for 24 h ±2 h at 44.5°C ±0.5°C. The presence of typical blue colonies was interpreted as evidence of the presence of fecal coliforms. Counts of these colonies were made for the most appropriate dilution, and recorded in terms of fecal coliforms per 100 mL of water sample.

(c) Fecal Streptococci (FS)

Fecal streptococcal counts were performed on Millipore (HA)* membrane filters (47 mm diameter, pore size 0.45 μ white gridded filter membranes), applied to KF Agar (Difco) and incubated for 48 ±3 h at 35°C. The development of colonies, normally dark red to pink in colour, was interpreted as evidence of fecal streptococci. Counts were determined from the most appropriate dilution and recorded in terms of fecal streptococci per 100 mL of water sample.

(d) Aerobic Heterotrophs (Heterotrophic plate-counts, HPC 20°C, and 35°C)

Using the spread-plate method, 0.1 mL of appropriate dilutions was spread on pre-dried plates of Plate-Count Agar (Difco) and incubated for either 48 h at 35°C or 5 days at 20°C. Plates having 30 to 300 colonies were counted for each dilution and results were reported as Colony Forming Units per mL (CFU/mL).

(e) Anaerobic Heterotrophs (ANA) (Total Anaerobes)

Using the spread-plate method, 0.1 mL of appropriate dilutions was spread on pre-dried, pre-reduced plates of Eugon agar (Difco) and incubated for 3 to 4 days at 30°C in an anaerobic chamber containing 5% H_2, 10% CO_2, and 85% N_2 gases with reazurin as the redox indicator. Plates having 30 to 300 colonies were counted for each dilution and results reported as CFU/mL.

(f) Total Fungi (RB/FUNGI) (Yeasts and Molds)

Using the spread-plate method, 1.0 mL of appropriate dilutions was spread onto pre-dried plates of Malt Extract Agar (Difco) containing 0.2 g/L each of streptomycin sulfate and oxytetracycline dihydrate (Sigma Chemical Co., St. Louis, MO) and incubated for 5 days at 20°C. All plates having 30 to 300 fungal colonies were counted for each dilution and results were reported as CFU/mL.

3.2.2. Physical and Chemical Analyses (Laboratory)

In general, the following analytical procedures listed in the NAQUADAT system and as outlined in the AEC Methods Manual for Analysis of Water and Wastes (2) were employed.

(A) Physical (Laboratory)	NAQUADAT CODE	METHODS
(1)	10301	pH - pH is determined electrometrically using a pH meter which has been calibrated with std. pH buffer solutions. A glass and a saturated calomel electrode are used as sensors.
(2)	02041:	Specific Conductance - Specific Conductance in the field is measured using a conductivity meter with platinized platinum electrodes, and corrected to 25°C. Laboratory conductivity measurements are completed at 25°C.
(3)	10453:	Residue, Filterable - Gravimetric micro method using a Whatman GF/C filtered sample. Microvolume of sample is weighed on a small dish and dried at 103-105°C.
(4)	00205:	Total Dissolved Solids (Calculated) - Calculated as follows; TDS = Na + K + 0.393 x Ca + 0.243 x TH + Si + SO_4 + Cl + 0.6 x T.Alk + 4.425 x (NO_2+NO_3).

(5) 10407: Residue, Non-filterable - Gravimetric micro method using a mechanically homogenized sample and filtered through a preweighed 0.45 μ filter. The filter is dried for one-half hour at 105°C and weighed.

(B) Chemical (Laboratory)

(a) Major Ions

(1) 10101: Alkalinity, Total - Potentiometric titration on a clear, settled sample using standardized acid (H_2SO_4) titrant. Titration is conducted to pH of 4.5 and the curve is corrected to a pH of 4.2.

(2) 17203: Chloride - Automated colorimetric method using ferric nitrate and mercuric thiocyanate. The reaction of the premixed reagent results in a red-colored complex which is measured spectrophotometrically at 480 nm.

(3) 16306: Sulphate - Automated colorimetric method using barium methylthymol blue complex. Sulfate reacts with barium, and methylthymol blue is released. Excess methylthymol blue is measured spectrophotometrically at 460 nm.

(4) 09107: Fluoride - Automated potentiometric method using a flow-through system with a specific ion combination electrode and a digital millivoltmeter.

(5) 11103: Sodium - Flame photometry with internal standard using an autoanalyzer system. A sample aliquot is mixed with a controlled portion of $LiNO_3$ and 1% H_2SO_4.
Solution is aspirated into a flame with the resulting emission measured at 589 nm and compared with the emission of the internal standard at 671 nm.

(6) 19103: Potassium - Flame photometry with internal standard using autoanalyzer system. A sample aliquot is mixed with a controlled portion of $LiNO_3$ and 1% H_2SO_4.
Solution is aspirated into a flame with the resulting emission measured at 768 nm and compared to an internal standard at 671 nm.

(7) 20110: Calcium - Atomic absorption with autoanalysis system. A 0.45 µ filtered sample is mixed with a $LaCl_3$ solution and aspirated into an acetylene-air flame. The absorbance is measured spectrophotometrically at 422.7 nm.

(8) 12302: Magnesium - Atomic absorption with autoanalysis system. A 0.45 µ filtered sample is mixed with a $LaCl_3$ solution and aspirated into an acetylene-air flame. The absorbance is measured spectrophotometrically at 309.3 nm.

(b) Nutrients

(1)	07106	Nitrogen, Particulate - Thermal conductivity (TC) method on N_2 produced from ignition of the sample on a support glass fibre filter. The pre-ignited filter containing residues is dried and ignited at 1050°C. The produced NO_x is reduced to N_2 using MnO_2 catalyst and measured by TC and compared to a standard sample.
(2)	07021:	Nitrogen, Total Kjeldahl - Automated phenate colorimetric determination. After the sample is mixed with H_2SO_4, K_2SO_4 and HgO, the resulting acid persulfate is block digested (200°C and 360°C). The resulting ammonia is coupled using the Bertholet reaction to produce a blue color, which is measured at 630 nm.
(3)	07105:	Nitrogen, Nitrite + Nitrate - Automated colorimetry on a 0.45 μ filtered sample. An aliquot of sample is mixed with EDTA and passed through a Cd column to reduce nitrate to nitrite ion. Sulfanilamide and N-1-Naphthelenediaminedihydrochloride are added to produce an azo complex. The intensity of the red color is measured at 520 nm.

(4) 07205: Nitrogen, Nitrite - Automated colorimetry on a 0.45 μ filtered sample. An aliquot of sample is mixed with sulphanilamide under acidic conditions to produce a diazo compound, which couples with N-(1-naphthyl) ethylene to form a soluble reddish-purple azo dye, which is measured at 520 nm.

(5) 07562: Nitrogen, Ammonia - Automated phenate colorimetric determination on a filtered sample. The filtered sample is then mixed with alkaline phenol, dipotassium hydrogen phosphate, disodium EDTA and NaClO with nitroprusside to produce a blue color, which is measured at 630 nm.

(6) 15421: Phosphorous, Total - An automated colorimetric analysis on a sample digested using a block digester after adding H_2SO_4, K_2SO_4 and HgO. The released orthophosphate is determined using automated phosphomolybdate colorimetry in which the absorbance of the blue color is determined at 880 nm.

(7) 14256: Orthophosphate - An automated colorimetric determination on a 0.45 μ filtered sample. An aliquot is mixed with reagent containing H_2SO_4, $(NH_4)_6Mo_7O_{24}$,

and ascorbic acid. The absorbance of the resulting molybdenum blue complex is measured at 880 nm.

(8) 06905: Carbon, Particulate - Gas chromatographic thermal conductivity (TC) method. A sample is collected on a pre-ignited GF/C paper and dried. The filter is placed in a tinfoil crucible and introduced into a high temperature (1050°C) combustion tube and ignited. The produced CO_2 is measured by TC and compared to a standard sample.

(9) 06107: Carbon, Dissolved Organic - Automatic colorimetric analysis on a settled sample after inorganic carbon has been removed by acidification and sparging. Organic carbon is released as CO_2 after UV irradiation with a persulphate solution. The CO_2 is absorbed into a borate-buffered solution of phenolphthalein. The loss of color is measured spectrophotometrically at 550 nm.

(10) 08304: Oxygen Demand, Chemical - Semi-automated colorimetric method. Sample is treated with H_2SO_4-$AgSO_4$ and $K_2Cr_2O_7$. The mixture is sealed in an ampule and digested at 150°C for 2 hours. The produced Cr^{3+} is measured at 600 nm.

(11) 08202: Oxygen Demand, Biochemical - Sample is homogenized and aerated to ensure availability of O_2. If sample is bacterially sterile, it is inoculated. The resulting solution is bottled and incubated at 20°C for 5 days. Decrease in O_2 concentration is determined by taking the difference in measured O_2 before and after incubation, using an O_2 selective ion electrode.

(c) Metals

(1) 13306: Aluminum - The sample is acidified to <pH 2 in the field and left overnight. An aliquot is adjusted to pH 6.0 with buffer and the aluminum is extracted with ethyl propionate containing 8-hydroxyquinoline. The solvent is aspirated into the flame of an atomic absorption spectrophotometer and the absorbance is measured at 309.2 nm and compared to identically prepared standards. For other metals, samples are acidified to <pH 2 in the field and left overnight. An aliquot of sample is digested with (1) conc. HCl and (2) aqua regia, and then diluted to 20% of its original aliquot volume. The concentrated sample is aspirated into the argon plasma of an inductively coupled emission spectrophotometer and the emission

intensity is electronically compared to identically prepared standards at the following wavelengths.

(2)	04103	Beryllium	313.8 nm
(3)	48009	Cadmium	228.8 nm
(4)	27009	Cobalt	228.6 nm
(5)	24009	Chromium	267.7 nm
(6)	29009	Copper	324.7 nm
(7)	25003	Manganese	257.6 nm
(8)	42009	Molybdenum	202.0 nm
(9)	28009	Nickel	231.6 nm
(10)	23009	Vanadium	292.4 nm
(11)	30009	Zinc	213.8 nm

(12) 82302: Lead - The sample is acidified to <pH 2 in the field and left overnight. An aliquot is adjusted to pH 4.75 with buffer, and APDC solution is added. The chelated lead is extracted into MIBK and aspirated into the flame of an atomic absorption spectrophotometer. The absorbance is measured at 283.3 nm and compared to identically prepared standards.

(13) 26304: Iron - A sub-sample is acidified to <pH 2 in the laboratory and left overnight. The solution is aspirated directly into the flame of an atomic absorption spectrophotometer and the absorbance measured at 248.3 nm and compared with those of identically prepared standards.

3.3 Statistical Procedures

The statistical methods used in this study are standard techniques, such as those found in Box *et al*. (8). Data from all feedlot surveys were analyzed using statistical methods described below.

(a) Descriptive Statistics

Geometric means (GMs) were estimated for each station at each feedlot for each survey. This was done by transforming the observed microbial counts to a logarithmic base 10 scale. This was done to homogenize the variances, reduce proportionality between variances and means, increase the normality and decrease the degree of skew in the data. All subsequent statistical analyses were done on the $\log_{10}$ transformed data.

The $\log_{10}$ transformation also satisfied the assumptions of the regression and analysis-of-variance methods which were used extensively in this study. These assumptions are: normality of data, homogeneity of variances, and additivity of the data for treatment effects in the model.

(b) Analysis-of-Variance

The effect of various independent discrete variables, such as sampling-stations within feedlots and seasons on microbial parameters, was studied by the analysis-of-variance method. In this technique, the total variation in the microbial counts is split into different components, and these are then tested for statistical significance by the residual or unexplained component.

(c) Distance-Decay Model

The variability in microbial counts from the impact station to various downstream sampling-stations was studied by the distance-dependent-decay model (13). For these analyses, data from the pre-impact sampling-stations were deleted and the distance at the impact station was assumed to be zero metres.

(d) Stepwise-Regression Analysis

The effect of 23 independent physical and chemical parameters on microbial counts was studied by using the stepwise-regression technique. This approach selects the independent variable(s) that maximizes R^2 (coefficient-of-determination) values. That means all independent variables are tested for their relative importance in accounting for maximum possible variation in microbial counts, and only those found to be statistically significant at a prespecified α level are permitted to stay in the final equation. This is a standard statistical technique, which permits all independent variables to express their relationships with the dependent variable (8, 11).

3.3.1 Sampling-Station Effects

The differences in microbial concentrations among sampling stations for feedlots surveyed in 1983, 1984 and 1985 were statistically analyzed by the analysis-of-variance method. The model used for each feedlot survey and for each microbial parameter was:

$$\log Y_{ijk} = \mu + A_i + B_{i(j)} + e_{ijk}$$

where Y_{ijk} = microbial counts of k-th replicate of j-th sample of i-th station.

μ = general population mean.

A_i = a fixed effect of sampling-stations ($i = 1..6$).

$B_{i(j)}$ = fixed effect of j-th sample within i-th station ($j = 1..4$).

e_{ijk} = random error associated with each observation $N(0,\sigma^2)$.

Station means were further analyzed statistically by the least-significant-difference method. Means not found different at $P \leq 0.05$ were assigned a similar alphabetical superscript.

3.3.2 Seasonal Effects

The effect of season (spring-runoff, storm-event, dry-weather) on microbial counts from each station for the pooled data was studied by the analysis-of-variance method. The model for each feedlot and for a particular microbial parameter was similar to the above model except for the A_i and $B_{(i)j}$ variables as follows:

$$\log Y_{ijk} = \mu + A_i + B_{(i)j} + e_{ijk}$$

where Y_{ijk} = microbial count of k-th replicate of j-th sample in i-th season.

μ = general population mean.

A_i = effect of i-th season ($i = 1,2,3$).

$B_{(i)j}$ = fixed effect of j-th sample within i-th season ($j = 1...4$).

e_{ijk} = random error associated with each observation, $N(0,\sigma^2)$.

This model was run separately for each feedlot and sampling station (1-6) pooled over all surveys (See data in Appendix 9.5). Seasonal data were created by pooling the data in the following order:

Season 1 (spring-runoff): Surveys Nos. 2, 3, 4, 11, 17, 18 and 19.

Season 2 (storm-event): Surveys Nos. 6, 12, 20, 21 and 22.

Season 3 (dry-weather): Surveys Nos. 5, 7, 8, 9, 10, 13, 14, 15 and 16.

Differences in seasonal means were further analyzed by the least-significant-difference method. Means not found different at $P \leq 0.05$ were assigned a similar alphabetical superscript.

3.3.3 Distance-Decay Model

A logarithmic distance-dependent decay function of the form,

$$M_d = A.10^{Bd} \text{....................} (I)$$

was fitted to the data where

M_d = microbial counts at distance d from the input source.

A = a constant.

d = distance to sampling-station in metres from the main source input.

B = distance-dependent decay coefficient.

Equation (I) was transformed to the logarithmic scale and was analyzed as a regression equation in the following form:

$$\log M_d = \log A + Bd \log_{10}$$

$$\log M_d = \log A + Bd \text{..................(II)}$$

All statistical analyses were done by using the Statistical Analysis System package (SAS), Version 5, running at the IBM 370 MV/OS operating system of Government of Alberta, Terrace Computing Centre.

In all tables showing the distance-decay analysis, values are provided for the number of observations (N), initial loading (log A and antilog A), decay coefficient (B), standard error of the decay coefficient (S.E.(B)), F-value of the decay-model, residual standard deviation (σ_e)of the model, coefficient-of-determination (R^2), and the extrapolated distance required to reduce the microbial count to one. This extrapolation requires caution and assumes that conditions in the extrapolated region are identical to the sampling region.

3.3.4 Multiple-Regression Model

A multiple-regression (multivariate) model (8, 14) was used to derive predictive equations for determining fluctuations in microbial counts. It incorporated various environmental variables as predictors. A total of 23 independent physical and chemical predictor variables were available for incorporation into the regression equation (Table 3.2). Not all feedlots and sampling stations within each feedlot had complete information on all variables, however. Therefore, missing data considerably reduced the sample size for analysis.

The multiple-regression equation of the following form was used to fit the data:

$$Y = B_o + B_1X_1 + B_2X_2 + B_3X_3 + \ldots + B_p X_p + e \, .$$

where Y = microbial counts converted to $\log_{10}$ scale.

B_o = intercept.

$B_1 \ldots B_p$ = regression parameters. ($p = 1 \ldots 23$).

$X_1 \ldots X_p$ = independent predictor variables.

e = random error associated with each observation.

In all tables of multiple-regression analysis, values are provided for the number of observations (N), coefficient-of-determination (R^2), mean standard error (M.S.E.), significant predictor variables (Xi), and regression coefficients (B-value).

Table 3.2. List of variables used in the multiple-regression equation to predict microbial counts

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(a) INDEPENDENT VARIABLES

(1)	DIST:	Distance between impact and sampling-stations
(2)	TEMP:	Water temperature (C)
(3)	DO_2:	Dissolved oxygen
(4)	TURB:	Turbidity
(5)	pH:	Water pH
(6)	SCOND:	Specific conductivity
(7)	FR:	Filterable residue
(8)	TDS:	Total dissolved solids
(9)	NFR:	Non-filterable residue
(10)	PARTN:	Particulate nitrogen
(11)	TKN	Total Kjeldahl nitrogen
(12)	NO_2+NO_3:	Nitrite + Nitrate nitrogen
(13)	NH_3:	Ammonia nitrogen
(14)	TP:	Total phosphorous
(15)	OP:	Orthophosphate
(16)	PARTC:	Particulate carbon
(17)	DOC:	Dissolved organic carbon
(18)	COD:	Chemical oxygen demand
(19)	BOD:	Biological oxygen demand
(20)	R1D:	Total rainfall within 1 day before sampling (mm)
(21)	R2D:	Total rainfall within 2 days before sampling (mm)
(22)	R3D:	Total rainfall within 3 days before sampling (mm)
(23)	R7D:	Total rainfall within 7 days before sampling (mm)

Table 3.2. (cont'd.). List of variables used in the multiple-regression equation to predict microbial counts

b) DEPENDENT VARIABLES

(1)	log HPC35	Aerobic heterotrophs (Heterotrophic plate-counts, 35°C)
(2)	log HPC20:	Aerobic heterotrophs (Heterotrophic plate-counts, 20°C)
(3)	log ANA:	Anaerobic heterotrophs
(4)	log RB: (FUNGI)	Total fungi
(5)	log TC:	Total coliforms
(6)	log FC:	Fecal coliforms
(7)	log FS:	Fecal streptococci

4.0 RESULTS AND DISCUSSION

Results of all surveys conducted at each feedlot under various hydrological conditions are described and discussed separately for the individual feedlot. As well, major findings of surveys are discussed with regard to fluctuations in microbial and chemical loadings caused by (a) station, and (b) seasonal influences. In addition, microbiological and chemical data for each feedlot are presented in statistical terms for the purpose of developing predictive equations that describe the fate of microorganisms during downstream transport.

4.1 Summary of Feedlot Surveys

During the study period (1983 to 1985), 21 surveys were conducted at the four feedlot sites (Table 4.1). Seven surveys were conducted under spring-runoff conditions, five surveys under storm-event conditions, and nine surveys under dry-weather conditions.

During 1983, four surveys were conducted under dry-weather conditions because the summer was unusually dry and lacked sufficient rainfall to produce significant runoff. In addition, representative spring-runoff surveys could not be conducted on any of the feedlot sites because little or no snowfall had accumulated during the winter of 1982-1983.

Table 4.1. Summary of feedlot surveys conducted during 1983, 1984 and 1985

FEEDLOT	SURVEY CONDITIONS AND DATES CONDUCTED			NO. OF SURVEYS PER FEEDLOT
	SPRING RUNOFF	STORM EVENT	DRY WEATHER	
Palmer Ranch, Waterton, AB	15 March, 1983 30 April, 1984 26 April, 1985	12 August, 1985	26 October, 1983 22 October, 1984	6
Prime Feeders Ltd., Fort Macleod, AB	29 April, 1983	16 August, 1985	13 September, 1983 28 August, 1984	4
Wes Yanke Ranch, Medicine Hat, AB	26 March, 1985	13 September, 1985	12 July, 1983 27 September, 1983 18 September, 1984	5
Adams Ranch Ltd., Czar, AB	19 April, 1983 9 April, 1985	19 June, 1983 7 June, 1984	4 October, 1983 1 October, 1984	6
NO. OF SURVEYS PER CONDITION	7	5	9	21

In 1984, four surveys were conducted under dry-weather conditions because the summer was atypically dry for southern Alberta. Moreover, no representative storm-event surveys were conducted at the three feedlot sites in that area during 1984.

During 1985, six surveys were conducted; three were storm-event surveys and three were spring-runoff surveys.

4.2 Palmer Ranch, Waterton

Six surveys were conducted at Palmer Ranch, Waterton (Table 4.1). Three of these were spring-runoff surveys. They were conducted on the following dates: (1) March 15, 1983 after a snowfall (20 to 25 cm snow within a 10 day period), which melted very rapidly and left the feedlot surface wet and soggy at the time of sampling; (2) April 30, 1984 after a snowfall (10 cm within a 2 day period), which melted fairly quickly; and (3) April 26, 1985 following a snowfall equivalent to 1.1 cm precipitation. One storm-event survey was conducted on August 12, 1985 after 6.3 cm of precipitation (rainfall) was recorded within a 3-day-period. Finally, two dry-weather surveys were conducted; one on October 26, 1983 and the other on October 22, 1984 following very dry summer seasons in both years.

4.2.1 Microbiological Analyses

Major microbiological findings of all surveys conducted at Palmer Ranch are discussed according to various parameter groups representing seasonal and station loadings in terms of geometric means (GMs) (e.g. Tables 4.2 and 4.3, respectively).

(a) Pollution-Indicator Bacteria

(i) Levels of TC, FC, and FS at most stations were lower (Table 4.2) during the spring-runoff surveys than during storm-event and dry-weather surveys.

(ii) During all spring-runoff surveys, a small but significant ($P \leq 0.05$) impact of the feedlot was demonstrated at Station 3 (impact station) where TC levels were higher than at both Station 1 (pre-impact) and Station 4 (influence) (Table 4.3). This impact was also reflected in the elevated FC levels during the 1985 spring survey, and by FS levels during the 1984 and 1985 spring-runoff surveys.

(iii) During the storm-event survey, densities of TC, FC, and FS were higher than other types of surveys (Table 4.2). Moreover, a significant impact of feedlot runoff was observed on concentrations of PIB, particularly with FC levels that exceeded the maximum limits for Canadian/Alberta recreational water quality (2, 6). For example, levels of TC, FC and FS measured at Station 3 (810; 530 and 2,100/100 mL, respectively) were substantially higher than those observed at Station 1 (88; 89 and 71/100 mL, respectively) and Station 4 (150; 120 and 220/100 mL, respectively). While densities of FC at Station 4 returned to acceptable limits, levels of all PIB downstream at Station 6 surpassed those of Station 3. The presence of a second potential source of microbial input during the storm-event survey, particularly one very close to the Waterton reservoir recreational area, points out that the Palmer Ranch feedlot may not be the only contributor to water

Table 4.2. Seasonal loadings (geometric means) of microbial levels at Palmer Ranch

MICROBIAL PARAMETER		SURVEY TYPE	STATION					
			PRE-IMPACT		IMPACT	INFLUENCE	POST-IMPACT	
			1	2	3	4	5	6
TOTAL COLIFORMS per 100 mL		a) Spring runoff	5^{c}	6^{c}	67^{a}	16^{b}	8^{c}	$11^{b.c}$
		b) Storm event	88^{d}	$120^{c.d}$	810^{a}	150^{c}	250^{b}	880^{a}
		c) Dry weather	110^{b}	22^{d}	160^{a}	59^{c}	$50^{c.d}$	32^{d}
FECAL COLIFORMS per 100 mL		a) Spring runoff	1^{b}	1^{b}	14^{a}	2^{b}	2^{b}	1^{b}
		b) Storm event	89^{e}	88^{e}	530^{b}	120^{d}	240^{c}	840^{a}
		c) Dry weather	$6^{b.c}$	2^{c}	41^{a}	15^{b}	8^{b}	4^{c}
FECAL STREPTOCOCCI per 100 mL		a) Spring runoff	3^{d}	$6^{c.d}$	$12^{b.c}$	$5^{c.d}$	$5^{c.d}$	34^{a}
		b) Storm event	71^{e}	160^{d}	2100^{b}	220^{c}	1900^{b}	5800^{a}
		c) Dry weather	680^{a}	12^{c}	720^{a}	280^{a}	250^{a}	55^{b}
HETEROTROPHS (AEROBIC) per mL	20°C	a) Spring runoff	850^{c}	3200^{b}	4700^{a}	1000^{c}	840^{c}	440^{d}
		b) Storm event	1300^{f}	1800^{e}	18000^{a}	3500^{c}	2900^{d}	4000^{b}
		c) Dry weather	760^{d}	2300^{b}	6200^{a}	860^{d}	1100^{c}	$880^{c.d}$
	35°C	a) Spring runoff	49^{d}	340^{b}	970^{a}	110^{c}	90^{c}	$75^{c.d}$
		b) Storm event	400^{e}	720^{d}	8200^{a}	810^{c}	820^{c}	1300^{b}
		c) Dry weather	100^{c}	420^{b}	830^{a}	$59^{c.d}$	21^{e}	46^{d}
ANAEROBES per mL		a) Spring runoff	25^{b}	26^{b}	98^{a}	27^{b}	20^{c}	16^{c}
		b) Storm event	280^{d}	330^{c}	1000^{a}	370^{c}	610^{b}	1000^{a}
		c) Dry weather	83^{b}	39^{c}	260^{a}	67^{b}	90^{b}	74^{b}
TOTAL FUNGI (Yeast & Molds) per mL		a) Spring runoff	9^{d}	45^{b}	92^{a}	17^{c}	$11^{c.d}$	7^{e}
		b) Storm event	13^{e}	42^{b}	270^{a}	28^{c}	29^{c}	20^{d}
		c) Dry weather	2^{d}	10^{b}	31^{a}	4^{c}	3^{c}	4^{c}

$^{a.b.c.d.e.f}$ Station means with same superscript are not significantly different at $P < 0.05$.

Table 4.3. Station loadings (geometric means) of microbial levels at Palmer Ranch

MICROBIAL PARAMETER	SURVEY TYPE	STATION PRE-IMPACT 1	STATION PRE-IMPACT 2	STATION IMPACT 3	STATION INFLUENCE 4	STATION POST-IMPACT 5	STATION POST-IMPACT 6
TOTAL COLIFORMS per 100 mL	Spring runoff 15/3/83	2^{b}	2^{b}	48^{a}	8^{b}	2^{b}	--
	Spring runoff 30/4/84	13^{c}	$16^{b,c}$	34^{a}	$23^{a,b}$	$16^{b,c}$	12^{c}
	Spring runoff 26/4/85	7^{d}	5^{d}	180^{a}	20^{b}	$15^{b,c}$	10^{c}
	Storm event 12/8/85	88^{d}	$120^{c,d}$	810^{a}	150^{c}	250^{b}	880^{a}
	Dry weather 26/10/83	270^{a}	36^{b}	230^{a}	60^{b}	120^{b}	--
	Dry weather 22/10/84	45^{b}	14^{e}	110^{a}	51^{b}	22^{d}	32^{c}
FECAL COLIFORMS per 100 mL	Spring runoff 15/3/83	1^{a}	1^{a}	6^{a}	0^{a}	1^{a}	--
	Spring runoff 30/4/84	0^{b}	2^{a}	5^{a}	0^{b}	0^{b}	2^{b}
	Spring runoff 26/4/85	1^{e}	1^{e}	120^{a}	7^{b}	4^{c}	2^{d}
	Storm event 12/8/85	89^{e}	88^{e}	530^{b}	120^{d}	240^{c}	840^{a}
	Dry weather 26/10/83	2^{b}	2^{b}	20^{a}	$8^{a,b}$	$7^{a,b}$	--
	Dry weather 22/10/84	21^{b}	3^{d}	83^{a}	28^{b}	9^{c}	4^{d}
FECAL STREPTOCOCCI per 100 mL	Spring runoff 15/3/83	0	0	0	0	0	--
	Spring runoff 30/4/84	38^{c}	46^{c}	210^{a}	56^{c}	100^{b}	43^{b}
	Spring runoff 26/4/85	2^{e}	37^{b}	90^{a}	9^{d}	8^{d}	13^{c}
	Storm event 12/8/85	71^{e}	160^{d}	2100^{b}	220^{c}	1900^{b}	5800^{a}
	Dry weather 26/10/83	4800^{a}	40^{d}	290^{c}	510^{b}	410^{b}	--
	Dry weather 22/10/84	98^{c}	4^{e}	1800^{a}	150^{b}	160^{b}	55^{d}

Table 4.3 (cont'd). Station loadings (geometric means) of microbial levels at Palmer Ranch

MICROBIAL PARAMETER		SURVEY TYPE	STATION					
			PRE-IMPACT		IMPACT	INFLUENCE	POST-IMPACT	
			1	2	3	4	5	6
HETEROTROPHS (AEROBIC)per mL	20°C	Spring runoff 15/3/83	2400^{b}	9200^{a}	2300^{b}	2400^{b}	2800^{b}	--
		Spring runoff 30/4/84	$580^{c,d}$	2400^{b}	4300^{a}	670^{c}	440^{e}	$530^{d,e}$
		Spring runoff 26/4/85	$460^{d,e}$	1600^{b}	10400^{a}	670^{c}	490^{d}	370^{e}
		Storm event 12/8/85	1300^{f}	1800^{e}	18000^{a}	3500^{c}	2900^{d}	4000^{b}
		Dry weather 26/10/83	$960^{b,c}$	2800^{a}	3700^{a}	670^{c}	1300^{b}	--
		Dry weather 22/10/84	600^{d}	1930^{b}	11000^{a}	1100^{c}	980^{c}	880^{c}
	35°C	Spring runoff 15/3/83	100^{c}	660^{b}	990^{a}	$120^{c,d}$	160^{d}	--
		Spring runoff 30/4/84	18^{e}	130^{b}	350^{a}	$89^{b,c}$	39^{d}	$45^{c,d}$
		Spring runoff 26/4/85	90^{d}	450^{b}	2700^{a}	$114^{d,c}$	120^{c}	125^{c}
		Storm event 12/8/85	400^{e}	720^{d}	8200^{a}	810^{c}	820^{c}	1300^{b}
		Dry weather 26/10/83	180^{b}	700^{a}	760^{a}	50^{c}	4^{d}	--
		Dry weather 22/10/84	$58^{d,e}$	230^{b}	1100^{a}	$77^{c,d,e}$	100^{c}	46^{e}
ANAEROBES per mL		Spring runoff 15/3/83	30^{a}	32^{a}	30^{a}	30^{a}	30^{a}	--
		Spring runoff 30/4/84	19^{b}	23^{b}	200^{a}	10^{b}	14^{b}	17^{b}
		Spring runoff 26/4/85	29^{b}	$25^{a,b}$	150^{a}	$23^{a,b}$	$20^{a,b}$	15^{c}
		Storm event 12/8/85	280^{d}	330^{c}	1000^{a}	370^{c}	610^{b}	1000^{a}
		Dry weather 26/10/83	$130^{a,b}$	46^{d}	170^{a}	$78^{c,d}$	$100^{b,c}$	--
		Dry weather 22/10/84	$51^{b,c}$	33^{c}	390^{a}	58^{b}	79^{b}	74^{b}
TOTAL FUNGI (Yeast & Molds) per mL		Spring runoff 15/3/83	<30	<30	<30	<30	<30	--
		Spring runoff 30/4/84	15^{d}	130^{b}	540^{a}	42^{c}	$24^{c,d}$	20^{d}
		Spring runoff 26/4/85	2^{d}	13^{b}	49^{a}	5^{c}	3^{c}	3^{c}
		Storm event 12/8/85	13^{e}	42^{b}	270^{a}	28^{c}	29^{c}	20^{d}
		Dry weather 26/10/83	2^{b}	7^{b}	21^{a}	2^{b}	2^{b}	--
		Dry weather 22/10/84	3	15	45^{a}	7	4	4

^{a,b,c,d,e,f} Station means with same superscript are not significanly different at $P < 0.05$.

quality impact in the Waterton River under storm-event conditions. Furthermore, it appears that most of the TC were of fecal origin because the FC counts were equal to approximately 65% of the TC counts at Station 3 and 100% of the counts at Station 6.

(iv) Dry-weather samples contained the highest densities of PIB, particularly FS levels. In general, a major adverse impact of feedlot runoff on the microbiological water-quality was not apparent (Table 4.2). A small increase in levels of TC, FC and FS at Station 3 was observed, however, during the fall dry-weather survey of 1984 (Table 4.3).

(b) Heterotrophic Bacteria

(i) During the storm-event survey, levels of heterotrophic bacteria at most stations were approximately one log level higher than those obtained during spring-runoff and dry-weather surveys (Table 4.2). Significantly higher ($P \leq 0.05$) densities of aerobic (20°C, 35°C) and anaerobic heterotrophs were observed at Station 3 (18,000, 8,200 and 1,000/mL, respectively) than at Station 1 (1,300, 400 and 280/mL, respectively). This suggests substantial loadings of heterotrophs from feedlot and associated runoff during storm-event conditions (Table 4.3).

(ii) Densities of heterotrophic bacteria were generally higher during dry-weather surveys than during spring-runoff surveys. Although counts were generally low in both types of surveys, some impact of feedlot runoff was observed on their levels. For example, as shown in Table 4.2, during dry-weather surveys, levels of aerobic (20°C, 35°C) and anaerobic heterotrophic bacteria were significantly higher at Station 3 (6200, 830 and 260/mL, respectively) than at Station 1 (760, 100 and 83/mL, respectively). Likewise, during spring-runoff surveys, overall densities (GMs) (Table 4.2) of aerobic (20°C, 35°C) and anaerobic heterotrophs were significantly higher at Station 3 (4,700, 970 and 98/mL, respectively) than at Station 1 (850, 49 and 25/mL, respectively). This impact was also observed during individual surveys (Table 4.3) with the exception of densities of aerobic (20°C) heterotrophic bacteria during the March 15, 1983 survey.

(c) Total Fungi (Yeasts and Molds)

(i) During all types of surveys (Table 4.2), total fungal densities were relatively low (2 to 270 CFU/mL). A varying degree of differences in counts was noted at Station 3, however, compared to counts at Station 1. This indicated some affect from feedlot runoff. The greatest difference occurred during the summer storm-event survey where fungal densities at Station 3 (270 CFU/mL) were significantly higher ($P \leq 0.05$) than those at Station 1 (13 CFU/mL) (Table 4.2).

4.2.2 Physical and Chemical Analyses

All the raw data for physical and chemical parameters, which was obtained from surveys conducted at Palmer Ranch, are presented in the unpublished data appendix. Some selected data, indicating seasonal loadings, are presented in Table 4.4. Major findings with regard to station loadings within individual surveys, as well as seasonal loading variations, are discussed here.

(a) Station Loadings

(i) Physical Parameters

The pH and specific conductance of these waters were moderately low, with little variation from season to season and station to station. The non filterable residues (NFR) were very low and essentially equivalent between stations with some minor impact in the 1984 surveys. The specific conductance was consistently higher at Station 3, indicating some additional loading of dissolved solids (Table 4.4).

(ii) Major Ions

The predominant ions found were Ca, Mg, and HCO_3^- (T.ALK), with slightly elevated levels at Station 3.

(iii) Nutrients

Nutrient concentrations were generally low at all stations. A small increase in TKN and occasionally elevated levels of NO_2+NO_3 and NH_3 were noted at Station 3. This suggested probable feedlot affects on the water course.

(iv) Metals

The concentration of metals at all stations was very low. Trace increases in iron were noted at Station 3; otherwise no station-to-station variation was evident. A significant contribution of metals by the feedlot to the receiving waters was not apparent.

Table 4.4. Seasonal loadings of chemical levels at Palmer Ranch

CHEMICAL PARAMETER	SURVEY DATE	STATION PRE-IMPACT 1	 PRE-IMPACT 2	 IMPACT 3	 INFLUENCE 4
TDS mg/L	a) Spring runoff 15/3/83	–	118	152	115
	b) Dry weather 26/10/83	103	120	160	126
	c) Spring runoff 30/4/84	–	113	150	93
	d) Dry weather 22/10/84	–	117	154	108
	e) Spring runoff 26/4/85	92	112	152	99
	f) Storm event 12/8/85	91	111	121	100
NFR mg/L	a) Spring runoff 15/3/83	–	3	3	6
	b) Dry weather 26/10/83	<2	<2	3	<2
	c) Spring runoff 30/4/84	–	8	13	4
	d) Dry weather 22/10/84	–	5	16	5
	e) Spring runoff 26/4/85	<2	6	6	5
	f) Storm event 12/8/85	3	3	6	6
S. COND. µS/cm	a) Spring runoff 15/3/83	–	228	298	201
	b) Dry weather 26/10/83	208	236	306	242
	c) Spring runoff 30/4/84	–	231	312	191
	d) Dry weather 22/10/84	194	224	296	209
	e) Spring runoff 26/4/85	190	226	305	201
	f) Storm event 12/8/85	174	215	262	191
TKN mg/L as N	a) Spring runoff 15/3/83	–	<0.050	0.080	0.160
	b) Dry weather 26/10/83	0.14	0.10	0.12	0.10
	c) Spring runoff 30/4/84	–	0.180	0.190	0.080
	d) Dry weather 22/10/84	0.12	0.100	0.240	0.080
	e) Spring runoff 26/4/85	0.05	0.280	0.027	0.100
	f) Storm event 12/8/85	0.12	0.140	0.240	0.160
DOC mg/L as C	a) Spring runoff 15/3/83	–	1.0	1.0	0.9
	b) Dry weather 26/10/83	<0.4	<0.4	<0.4	0.4
	c) Spring runoff 30/4/84	–	<0.4	0.9	0.7
	d) Dry weather 22/10/84	2.0	1.8	1.8	1.8
	e) Spring runoff 26/4/85	1.0	0.7	1.6	1.2
	f) Storm event 12/8/85	<0.4	1.0	1.0	0.6
COD mg/L	a) Spring runoff 15/3/83	–	<5.0	<5.0	<5.0
	b) Dry weather 26/10/83	<5.0	<5.0	<5.0	<5.0
	c) Spring runoff 30/4/84	–	<5.0	<5.0	7.8
	d) Dry weather 22/10/84	<5.0	<5.0	<5.0	<5.0
	e) Spring runoff 26/4/85	<5.0	<5.0	<5.0	<5.0
	f) Storm event 12/8/85	<5.0	<5.0	15.4	5.6
T. ALK mg/L as CaCO$_3$	a) Spring runoff 15/3/83	–	121	148	107
	b) Dry weather 26/10/83	103	117	150	116
	c) Spring runoff 30/4/84	–	117	153	95
	d) Dry weather 22/10/84	97	115	150	110
	e) Spring runoff 26/4/85	91	112	143	96
	f) Storm event 12/8/85	87	109	131	96

(b) Seasonal Loadings

(i) Physical Parameters

The pH was virtually constant in all surveys. The specific conductance and TDS were constant from survey to survey, with a minor drop in values during the storm-event. NFR concentrations were very (e.g. <2 mg/L) low at all times.

(ii) Major Ions

As reflected by specific conductance measurements, the major ion concentrations were relatively low and essentially exhibiting little difference from survey to survey.

(iii) Nutrients

All nutrient levels were low and with little difference between seasonal surveys.

(iv) Metals

All metal concentrations for all surveys were at or below detectable levels. Therefore, no seasonal trends were apparent.

4.2.3 Statistical Analyses

(a) Distance-Decay Model

At Palmer Ranch, the influence and post-impact sampling stations were located at 320, 1370 and 2300 meters downstream from the impact station (Station 3). Data from pre-impact stations were deleted when distance-decay coefficients were estimated.

The results of distance-decay model analyses are presented in Table 4.5 for the pooled data, and in Tables 4.6-4.8 for the seasonal data. Decay coefficients (B-values) showed a highly significant ($P \leq 0.01$) negative effect of distance on the bacterial counts, except for the FS counts, for which the relationship was not significant (P >0.05). The coefficient-of-determination (R^2) values were quite low, ranging from 0 to 24% (0.0061-0.2439, Table 4.5), indicating that distance alone is not sufficient to explain the variability in microbial counts. The distance required to reduce the count to a hypothetical value of 1 was 5.6 km to 13 km.

A comparison of seasonal distance-decay coefficients (Tables 4.6-4.8) showed that in most cases there was a significant negative relationship between distance and microbial counts, except for the FS counts in spring runoff, and anaerobic heterotrophs (ANA) and TC counts in the storm-event surveys. Also during the storm-event surveys, the counts of FC and FS were elevated at all stations downstream of the feedlots, indicating a significant impact, as depicted by the positive decay coefficients. The R^2 values showed a sizeable variation, from 1.8 to 46.3% during the seasonal events.

The hypothetical distance to reduce the bacterial counts to 1 was highest in the storm-event survey, mainly because of higher initial loadings. For the dry-weather and spring-runoff surveys, these hypothetical distance values were similar. With positive decay coefficients, microbial counts would increase rather than decrease as a function of the distance from impact Station 3. While useful information is provided by the distance-decay model, it is evident that about 75% of the variation in microbial counts observed during individual surveys and seasonal-type surveys cannot be explained by this model.

Table 4.5. Logarithmic distance-decay coefficients[a] for all data from Palmer Ranch

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σ_e	R^2	DISTANCE TO 1 COUNT (km)[b]
LOG HPC 35	260	2.658894 (455)	-.000365[c]	.000052	48.20	.727982	.1574	7.28
LOG HPC 20	263	3.497258 (3142)	-.000284[c]	.000031	84.23	.429614	.2439	12.31
LOG ANA	261	2.066192 (116)	-.000159[c]	.000045	12.25	.630604	.0451	12.99
LOG FUNGI	262	1.521012 (33)	-.000349[c]	.000043	63.89	.603345	.1972	4.35
LOG TC	132	1.851816 (71)	-.000186[c]	.000066	7.78	.655973	.0564	9.95
LOG FC	132	1.252781 (17)	-.000222[c]	.000093	5.59	.921761	.0412	5.64
LOG FS	150	1.619086 (41)	.000111	.000116	.92	1.189596	.0061	--

[a] Model: LOG Y = LOG A + BD

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] High significant ($P \leq 0.01$)

Table 4.6. Logarithmic distance-decay coefficients[a] for spring-runoff data from Palmer Ranch

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σ_e	R^2	DISTANCE TO 1 COUNT (km)[b]
LOG HPC 35	128	2.599956 (398)	-.000392[c]	.000050	61.37	.4876	.3275	6.63
LOG HPC 20	132	3.419153 (2625)	-.00036[c]	.000038	89.52	.3751	.4077	9.47
LOG FUNGI	132	1.671979 (46)	-.000409[c]	.000059	46.70	.5871	.2642	4.08
LOG ANA	129	1.771696 (59)	-.000291[c]	.000046	39.90	.4509	.2390	6.08
LOG TC	66	1.535010 (34)	-.000315[c]	.000065	23.21	.4537	.2661	4.87
LOG FC	66	.789653 (6)	-.000361[c]	.000078	20.92	.5474	.2463	2.18
LOG FS	84	.805433 (6)	.000149	.000121	1.50	.9089	.0180	-

[a] Model: LOG Y = LOG A + BD

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] Highly significant ($P \leq 0.01$)

Table 4.7. Logarithmic distance-decay coefficients[a] for storm-event data from Palmer Ranch

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σ_e	R^2	DISTANCE TO 1 COUNT (km)[b]
LOG HPC 35	48	3.436647 (2733)	-.000222[c]	.000062	12.81	.3910	.2177	15.48
LOG HPC 20	48	3.917745 (8274)	-.000204[c]	.000045	20.28	.2846	.3059	19.20
LOG ANA	48	2.782060 (605)	-.000060	.000033	3.20	.2110	.0649	46.36
LOG FUNGI	48	2.010869 (102)	-.000353[c]	.000057	37.83	.3606	.4512	5.69
LOG TC	24	2.504080 (319)	-.000105	.000078	1.82	.3465	.0765	--
LOG FC	24	2.357908 (227)	.000173[c]	.000073	5.58	.3269	.2022	--
LOG FS	24	2.811222 (647)	.000369[c]	.000097	14.38	.4334	.3952	--

[a] Model: LOG Y = LOG A + BD

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] Highly significant ($P \leq 0.01$)

Table 4.8. Logarithmic distance-decay coefficients[a] for the dry-weather data from Palmer Ranch

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σ_e	R^2	DISTANCE TO 1 COUNT (km)[b]
LOG HPC 35	84	2.411204 (257)	-.000552[c]	.000095	33.26	.7153	.2885	4.36
LOG ANA	84	2.167260 (146)	-.000161[c]	.000038	17.49	.2881	.1758	13.46
LOG HPC20	83	3.423026 (2648)	-.000264[c]	.000047	30.77	.3541	.2752	12.96
LOG FUNGI	82	1.056582 (11)	-.000322[c]	.000058	30.58	.4300	.2765	3.28
LOG TC	42	2.042643 (110)	-.000253[c]	.000053	22.50	.2819	.3599	8.07
LOG FC	42	1.467364 (29)	-.000409[c]	.000080	26.17	.4227	.3954	3.58
LOG FS	42	2.755208 (569)	-.000378[c]	.000064	34.46	.3401	.4628	7.28

[a] Model: LOG Y = LOG A + BD

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] Highly significant ($P \leq 0.01$)

(b) Multiple-Regression Model

Multiple-regression equations based on stepwise selection techniques are presented in Table 4.9 for the pooled data, and in Tables 4.10-4.12 for the seasonal data. All reported regression coefficients were highly significant ($P \leq 0.01$). In addition, values are provided on number of observations (N), coefficient-of-determination (R^2) and mean standard error (M.S.E.) of the model.

For the pooled data set (Table 4.9), several independent variables were found to be highly significant ($P \leq 0.01$). Therefore, they were retained in the final equation. These independent variables accounted for most of the variation in microbial counts of various parameters, as shown by the R^2 values, which ranged from 79 to 97%. From the correlation-coefficient analysis of the pooled data from Palmer Ranch, it was noticed that product-moment correlation-coefficients were higher than 0.9 between R1D and R2D, R1D and R3D and R2D and R3D. Because these three correlation coefficients were the only ones that were higher than 0.9, multicollinearity could be assumed to be insignificant for these data. Multicollinearity (when two variables statistically explain the same observation) in predictor variables can cause ill-conditioning of the model, with unstable coefficients. This can occur when predictor variables have a very high correlation coefficient ($r > 0.95$) among themselves, although this was not true in this case.

Multiple-regression equations for the seasonal surveys (Tables 4.10-4.12) identified several independent variables that significantly affected the microbial counts. It should be noted, however, that despite some commonalities, different predictor

Table 4.9. Multiple-regression equations based on pooled data from Palmer Ranch

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	1.1100	Intercept	-1.0241	Intercept	1.3365	Intercept	-4.6131	Intercept	-1.6067	Intercept	-2.5263	Intercept	-4.2580
FR	0.0044	DIST	-0.0002	TEMP	-0.0259	TEMP	0.1401	DIST	0.0002	DIST	0.0001	DIST	0.0002
NFR	0.0495	TURB	-0.4824	SCOND	0.0034	DO2	0.1768	DO2	0.1275	SCOND	0.0146	DO2	0.2939
PARTN	-0.7233	PH	0.3442	TP	25.3665	TURB	2.4958	TURB	2.6782	DOC	0.5295	PH	0.3937
NH3	2.6421	SCOND	0.0029	NO2NO3	-5.6861	FR	0.0050	SCOND	0.0094	TP	-28.5224	SCOND	-0.0045
OP	139.2819	FR	0.0044	R3D	0.0205	NFR	0.1090	BOD	-0.0547	NO2NO3	-5.9421	FR	0.0103
R1D	0.0401	NFR	0.0805			DOC	0.3198	NO2NO3	-7.6231	R3D	0.0314	PARTC	-0.3623
		TKN	-1.7225			COD	0.0790	R3D	0.0207			DOC	2.1560
		OP	69.0028			NO2	2.0312					NH3	11.6778
		NO2NO3	-3.3622			NO2NO3	7.3302					TP	27.9891
		R3D	0.0132									COD	-0.1167
												NO2	3.8835
												NO2NO3	-13.6058
												R1D	-1.1497
												R3D	0.5018
												R7D	-0.0618
N	250	N	251	N	249	N	250	N	126	N	130	N	138
R2	0.8039	R2	0.8981	R2	0.7941	R2	0.9054	R2	0.8575	R2	0.8346	R2	0.9726
M.S.E.	0.0754	M.S.E.	0.0233	M.S.E.	0.0610	M.S.E.	0.0507	M.S.E.	0.0602	M.S.E.	0.1296	M.S.E.	0.0377

Table 4.10. Multiple-regression equations based on spring-runoff data from Palmer Ranch

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	-0.1983	Intercept	-14.3021	Intercept	-5.8798	Intercept	-8.4507	Intercept	-5.2164	Intercept	-30.8928	Intercept	-24.3963
DIST	-0.0001	DIST	-0.0001	PH	0.6322	DIST	-0.0001	DIST	0.0002	DIST	0.0002	DIST	-0.0001
TURB	39.5459	DO2	0.1046	SCOND	0.0300	TEMP	0.2912	DO2	0.2724	TEMP	-0.0805	TEMP	0.3076
SCOND	-0.0351	TURB	-44.8115	FR	0.0117	DO2	0.3951	FR	0.0119	DO2	0.4762	DO2	0.7978
TDS	0.0834	PH	1.5373	TDS	-0.0564	TURB	60.0874	TDS	0.0100	TURB	-126.2401	TURB	74.8102
		FR	0.0317			SCOND	0.0541			PH	2.5078	PH	1.1116
						FR	-0.0044			FR	0.0589	SCOND	0.1051
												FR	0.0141
						TDS	-0.0880					TDS	-0.2042
N	108	N	108	N	105	N	108	N	54	N	58	N	65
R2	0.8112	R2	0.9043	R2	0.6583	R2	0.9476	R2	0.8257	R2	0.9202	R2	0.9594
M.S.E.	0.0579	M.S.E.	0.0239	M.S.E.	0.0631	M.S.E.	0.0296	M.S.E.	0.0635	M.S.E.	0.0388	M.S.E.	0.0390

Table 4.11. Multiple-regression equations based on storm-event data from Palmer Ranch

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	30.5276	Intercept	28.8581	Intercept	15.2343	Intercept	24.8009	Intercept	23.4762	Intercept	21.0209	Intercept	32.5359
TEMP	-1.1025	TEMP	-0.9716	TEMP	-0.4947	TEMP	-1.0103	TEMP	-0.8327	TEMP	-0.7146	TEMP	-1.2098
DO2	-1.4096	DO2	-1.3417	DO2	-0.6573	DO2	-1.1128	DO2	-1.1057	DO2	-1.0072	DO2	-1.5450
N	48	N	48	N	48	N	48	N	24	N	24	N	24
R2	0.9365	R2	0.9358	R2	0.8118	R2	0.8906	R2	0.8839	R2	0.8122	R2	0.9489
M.S.E.	0.0180	M.S.E.	0.0137	M.S.E.	0.0122	M.S.E.	0.0313	M.S.E.	0.0209	M.S.E.	0.0269	M.S.E.	0.0185

Table 4.12. Multiple-regression equations based on dry-weather data from Palmer Ranch

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	-28.0292	Intercept	-13.8886	Intercept	0.1187	Intercept	-15.8602	Intercept	-10.5744	Intercept	-21.1549	Intercept	-0.4[illegible]
DIST	-0.0007	DIST	-0.0004	DIST	-0.0002	DIST	-0.0001	TURB	-4.6095	DIST	0.0003	DIST	-0.0005
DO2	-0.2149	DO2	-0.2071	TEMP	-0.2531	TEMP	0.2012	PH	1.3770	DO2	-0.3154	TEMP	-0.5896
TURB	-7.5265	TURB	-5.2566	DO2	0.1738	DO2	-0.4422	SCOND	-0.0020	PH	3.1980	DO2	0.5505
PH	3.7093	PH	2.1555	TURB	-7.3894	PH	2.1913	FR	0.0166			TURB	-23.2869
FR	0.0241	SCOND	0.0036	SCOND	0.0117	FR	0.0144					SCOND	0.0163
		FR	0.0117									FR	0.0051
N	94	N	95	N	96	N	94	N	48	N	48	N	48
R2	0.7542	R2	0.8789	R2	0.6351	R2	0.8658	R2	0.9360	R2	0.6988	R2	0.9891
M.S.E.	0.0875	M.S.E.	0.0230	M.S.E.	0.0662	M.S.E.	0.0405	M.S.E.	0.0122	M.S.E.	0.1473	M.S.E.	0.0105

variables influenced different microbial parameters. For these equations, R^2 values were quite high, ranging from 63.5 to 98.9%. Also, these R^2 values were much higher compared to those obtained by the distance-decay model. This shows that regression equations are better predictors of microbial counts than those of the distance-decay model.

In summarizing the important predictor variables for this feedlot, it is evident that DIST, TEMP, pH, SCOND and TURB occurred more frequently than other variables, and they significantly affected the levels of various microbial parameters. Therefore, in any future monitoring programs and feedlot-impact studies, these variables should be emphasized.

4.3 Prime Feeders Ltd., Fort Macleod

Four surveys were conducted at Prime Feeders Ltd., Fort Macleod. They were as follows: (1) one spring-runoff survey conducted on April 29, 1983 (spring snow-melt) after a sudden snow storm, that deposited approximately 30 cm of snow that melted rapidly; (2) one storm-event survey conducted on August 16, 1985, following 4.4 cm of precipitation within a 3-day-period; and (3) two dry-weather surveys conducted on September 13, 1983 and August 28, 1984, following very dry spring and summer conditions.

4.3.1 Microbiological Analyses

The GMs (seasonal loadings) of values obtained for each parameter for all surveys conducted under spring-runoff, storm-event, and dry-weather conditions are presented in Table 4.13, while the GMs (station loadings) of parameters per station during individual surveys are presented in Table 4.14. The highlights of microbiological results for Prime Feeders Ltd., are discussed here in terms of seasonal and station loadings for various parameter groups.

(a) Pollution-Indicator Bacteria

(i) Densities of TC, FC and FS at all stations were higher during the storm-event survey than those observed during the spring-runoff and dry-weather surveys (Table 4.13).

(ii) During the storm-event survey, levels of TC and FC exceeded the acceptable limits (3 to 7 times) for Canadian/Alberta recreational water quality (2, 6). Any impact from feedlot runoff, however, was difficult to delineate because of the high counts observed at Station 1 (Table 4.14). The high TC and FC densities at Station 1 suggest the presence of another substantial microbial source upstream of the feedlot at the time of sampling. A significant difference in FS levels, however, was observed at Stations 2 (2,100 CFU/mL) and 3 (1,300 CFU/100 mL) compared to counts at Station 1 (730 CFU/100 mL) (Table 4.14). Again this suggests that the microbial input from the feedlot site may be of a different nature than the undefined upstream source.

(iii) During the spring-runoff survey, TC counts exceeded the guidelines for Canadian/Alberta recreational water quality (2, 6) at Stations 2 and 3 (1,600 and 2,300/100 mL, respectively) and were significantly higher than those obtained at Station 1 (440/100 mL). This impact was also reflected in the FS densities, but not in FC densities (Table 4.14).

Table 4.13. Seasonal loadings (geometric means) of microbial levels at Prime Feeders Ltd.

MICROBIAL PARAMETER		SURVEY TYPE	STATION					
			PRE-IMPACT	IMPACT		INFLUENCE	POST-IMPACT	
			1	2	3	4	5	6
TOTAL COLIFORMS per 100 mL		a) Spring runoff	440^{b}	1600^{a}	2300^{a}	300^{b}	370^{b}	—
		b) Storm event	$5200^{a,b}$	7000^{a}	4600^{b}	$5600^{a,b}$	4700^{b}	4400^{b}
		c) Dry weather	77^{b}	$220^{a,b}$	100^{b}	360^{a}	140^{b}	420^{a}
FECAL COLIFORMS per 100 mL		a) Spring runoff	$95^{a,b}$	120^{a}	83^{b}	70^{c}	$85^{b,c}$	—
		b) Storm event	$890^{a,b}$	1200^{a}	840^{b}	$700^{b,c}$	$640^{b,c}$	540^{c}
		c) Dry weather	23^{c}	110^{b}	43^{c}	320^{a}	$64^{b,c}$	28^{c}
FECAL STREPTOCOCCI per 100 mL		a) Spring runoff	$47^{b,c}$	100^{a}	55^{b}	42^{c}	$44^{b,c}$	—
		b) Storm event	730^{d}	2100^{a}	1300^{c}	1100^{c}	1700^{b}	2400^{a}
		c) Dry weather	130^{b}	730^{a}	180^{b}	670^{a}	760^{a}	870^{a}
HETEROTROPHS (AEROBIC) per mL	20°C	a) Spring runoff	24000^{b}	49000^{a}	55000^{a}	21000^{b}	20000^{b}	—
		b) Storm event	1300^{a}	$1200^{a,b}$	1100^{c}	1300^{a}	$1200^{b,c}$	1300^{a}
		c) Dry weather	$1600^{b,c}$	$1800^{a,b}$	1300^{c}	1900^{a}	1100^{d}	760^{a}
	35°C	a) Spring runoff	2100^{b}	4900^{a}	4000^{a}	1900^{b}	1600^{b}	—
		b) Storm event	1300^{b}	1300^{b}	1500^{a}	1400^{a}	1200^{c}	1400^{b}
		c) Dry weather	$1100^{a,b}$	$1100^{a,b}$	930^{b}	1300^{a}	650^{c}	370^{d}
ANAEROBES per mL		a) Spring runoff	380^{c}	510^{b}	760^{a}	330^{c}	340^{c}	—
		b) Storm event	530^{a}	540^{a}	500^{a}	430^{b}	49^{c}	39^{d}
		c) Dry weather	220^{a}	240^{a}	220^{a}	260^{a}	140^{b}	94^{b}
TOTAL FUNGI (Yeast & Molds) per mL		a) Spring runoff	430^{a}	500^{a}	350^{a}	75^{b}	80^{b}	—
		b) Storm event	13^{b}	13^{b}	15^{b}	14^{b}	12^{b}	22^{a}
		c) Dry weather	7^{b}	19^{a}	$11^{a,b}$	$11^{a,b}$	9^{a}	1^{c}

^{a,b,c,d} Station means with same superscript are not significantly different at $P < 0.05$.

Table 4.14. Station loadings (geometric means) of microbial levels at Prime Feeders Ltd.

MICROBIAL PARAMETER	SURVEY TYPE	STATION					
		PRE-IMPACT	IMPACT		INFLUENCE	POST-IMPACT	
		1	2	3	4	5	6
TOTAL COLIFORMS per 100 mL	Spring runoff 29/4/83	440^{b}	1600^{a}	2300^{a}	300^{b}	370^{b}	—
	Storm event 16/8/85	$5200^{a,b}$	7000^{a}	4600^{a}	5600	4700^{b}	4400^{b}
	Dry weather 13/9/83	310^{c}	640^{b}	520^{b}	860^{a}	530^{b}	—
	Dry weather 28/8/84	19^{d}	$75^{b,c}$	$20^{c,d}$	150^{b}	$38^{c,d}$	420^{a}
FECAL COLIFORMS per100 mL	Spring runoff 29/4/83	$95^{a,b}$	120^{a}	83^{b}	70^{c}	$85^{b,c}$	—
	Storm event 16/8/85	$890^{a,b}$	1200^{a}	840^{b}	$700^{b,c}$	$640^{b,c}$	540^{c}
	Dry weather 13/9/83	54^{d}	170^{c}	160^{c}	740^{a}	310^{b}	—
	Dry weather 28/8/84	10^{c}	68^{a}	12^{c}	140^{a}	$13^{b,c}$	28^{b}
FECAL STREPTOCOCCI per 100 mL	Spring runoff 29/4/83	$47^{b,c}$	100^{a}	55^{b}	42^{c}	$44^{b,c}$	—
	Storm event 16/8/85	730^{d}	2100^{a}	1300^{c}	1100^{c}	1700^{b}	2400^{a}
	Dry weather 13/9/83	560^{b}	1800^{a}	1400^{a}	1500^{a}	1500^{a}	—
	Dry weather 28/8/84	31^{c}	300^{b}	45^{c}	300^{b}	390^{b}	870^{a}

Table 4.14 (cont'd). Station loadings (geometric means) of microbial levels at Prime Feeders Ltd.

MICROBIAL PARAMETER		SURVEY TYPE	STATION					
			PRE-IMPACT	IMPACT		INFLUENCE	POST-IMPACT	
			1	2	3	4	5	6
HETEROTROPHS AEROBIC per mL	20°C	Spring runoff 29/4/83	24000^{b}	49000^{a}	55000^{a}	21000^{b}	20000^{b}	—
		Storm event 16/8/85	1300^{a}	1200^{a,b}	1100^{c}	1300^{a}	1200^{b,c}	1300^{a}
		Dry weather 13/9/83	1500^{c,d}	2000^{b}	1600^{c}	2400^{a}	1300^{d}	—
		Dry weather 28/8/84	1600^{a}	1600^{a}	1200^{a,b}	1600^{a}	900^{b,c}	760^{c}
	35°C	Spring runoff 29/4/83	2100^{b}	4900^{a}	4000^{a}	1900^{b}	1600^{b}	—
		Storm event 16/8/85	1300^{b}	1300^{b}	1500^{a}	1400^{a}	1200^{c}	1400^{b}
		Dry weather 13/9/83	750^{c,d}	940^{b}	790^{c}	1230^{a}	650^{d}	—
		Dry weather 28/8/84	1600^{a}	1300^{a,b}	1100^{b}	1300^{a,b}	650^{c}	370^{d}
ANAEROBES per mL		Spring runoff 29/4/83	380^{c}	510^{b}	760^{a}	330^{c}	340^{c}	—
		Storm event 16/8/85	530^{a}	540^{a}	500^{a}	430^{b}	49^{c}	39^{d}
		Dry weather 13/9/83	280^{a}	370^{a}	360^{a}	360^{a}	210^{b}	—
		Dry weather 28/8/84	180^{a}	160^{a}	140^{a,b}	180^{a}	90^{b}	94^{b}
TOTAL FUNGI (Yeast & Molds) per mL		Spring runoff 29/4/83	430^{a}	500^{a}	350^{a}	75^{b}	80^{b}	—
		Storm event 16/8/85	13^{b}	13^{b}	15^{b}	14^{b}	12^{b}	22^{a}
		Dry weather 13/9/83	<30	<30	<30	<30	<30	—
		Dry weather 28/8/84	2^{c}	12^{a}	4^{b}	4^{b}	3^{b}	1^{c}

^{a,b,c,d} Station means with same superscript within a survey are not significantly different at $P < 0.05$.

(iv) Levels of TC and FC at most stations were generally lower during the dry-weather surveys than those recorded in spring-runoff and storm-event surveys (Table 4.13).

(v) Little or no impact of feedlot runoff on levels of TC, FC or FS at Stations 2 and 3 in Willow Creek was demonstrated during either of the two dry-weather surveys (Table 4.14). In fact, counts at Stations 4, 5 and 6 were equal to, or significantly greater than, those observed at upstream stations. This anomaly was probably caused by fecal material from undefined sources. One likely source was the migratory birds that were seen in the vicinity of the sampling-stations during the survey.

(b) Heterotrophic Bacteria

(i) During the spring-runoff survey, populations of aerobic heterotrophic bacteria (particularly 20°C heterotrophs) were substantially elevated in comparison to those obtained during storm-event and dry-weather surveys. The levels of anaerobic heterotrophic bacteria, however, did not vary significantly among the three types of surveys (Table 4.13).

(ii) A measurable impact during the spring-runoff survey was demonstrated by significantly higher levels of both aerobic (20°C and 35°C) and anaerobic heterotrophs at Station 2 (49,000, 4,900 and 510/mL, respectively) and Station 3 (55,000, 4,000 and 760/mL, respectively) in comparison to those at Station 1 (24,000, 2,100 and 380/mL, respectively) (Table 4.14).

(iii) Densities of aerobic and anaerobic heterotrophic bacteria were generally low and remained relatively constant at all stations during the storm-event and dry-weather surveys. In addition, no significant impact was demonstrated during these surveys.

(c) Total Fungi (Yeasts and Molds)

(i) Levels of fungi (80 to 500 CFU/mL) at all stations were about ten times higher during the spring-runoff survey than those found during storm-event and dry-weather surveys (Table 4.14). No impact of feedlot runoff was detected in terms of fungal densities during any of these surveys.

4.3.2 Physical and Chemical Analyses

All raw data for physical and chemical parameters that were obtained from surveys conducted at Prime Feeders Ltd. are present in the unpublished data appendix. Some selected parameter data for these surveys, indicating seasonal loadings, are presented in Table 4.15. Major findings with regard to station loadings within individual surveys, as well as seasonal loading variations, are discussed here.

(a) Station loadings

(i) Physical parameters

The pH of the samples was moderately high and consistent between Stations 1, 3 and 5 (8.4-10.1 pH). The specific conductance was at an intermediate level and exhibited little change (400-722 µs/cm) between Stations 1, 3 and 5. Non-filterable residue (NFR) levels did not vary significantly from station station within each survey. There was no evidence that the feedlot affected the physical parameters present in the watercourse.

(ii) Major ions

The predominant ions consisted of Ca, Mg, Na, HCO_3^- (T.ALK), and $SO_4^=$. There was no significant differences in major ion concentrations between stations for each survey. In one survey (August 84 - dry-weather survey), the concentration of TDS decreased from pre-impact levels to impact levels (Table 4.15).

(iii) Nutrients

The nutrient levels were elevated above ambient at all stations; especially nitrogen parameters. Trends indicated a small contribution of TKN by the feedlot.

(iv) Metals

Only Fe, Mn and Al occurred at measurable concentrations. The concentrations were relatively constant between stations with no suggested contributions by the feedlot.

(b) Seasonal Loadings

(i) Physical Parameters

The pH during spring-runoff sampling was lower (8.5) than during storm-events sampling and dry-weather sampling (9.0-10.0 pH). The specific conductance remained relatively constant between events, with a small increase during dry-weather sampling. The NFR was significantly higher at all stations during spring-runoff sampling.

(ii) Major Ions

A small increase in the major ions was evident during one of the two dry-weather events. The remaining levels showed little change between events for this category.

Table 4.15. Seasonal loadings of chemical levels at Prime Feeders Ltd.

CHEMICAL PARAMETER	SURVEY DATE	STATION		
		PRE-IMPACT 1	IMPACT 3	POST-IMPACT 5
TDS mg/L	a) Spring runoff 29/4/83	240	252	252
	b) Dry weather 13/9/83	213	217	227
	c) Dry weather 28/8/84	481	401	346
	d) Storm event 16/8/85	301	303	294
NFR mg/L	a) Spring runoff 29/4/83	56	55	60
	b) Dry weather 13/9/83	5	6	7
	c) Dry weather 28/8/84	10	11	6
	d) Storm event 16/8/85	4	5	6
S. COND. µS/cm	a) Spring runoff 29/4/83	424	427	436
	b) Dry weather 13/9/83	399	406	417
	c) Dry weather 28/8/84	722	632	556
	d) Storm event 16/8/85	512	516	505
TKN mg/L as N	a) Spring runoff 29/4/83	0.48	0.46	0.62
	b) Dry weather 13/9/83	0.32	0.38	0.40
	c) Dry weather 28/8/84	1.24	1.20	1.32
	d) Storm event 16/8/85	1.04	1.24	1.20
DOC mg/L as C	a) Spring runoff 29/4/83	7.5	6.6	6.5
	b) Dry weather 13/9/83	4.2	4.1	5.0
	c) Dry weather 28/8/84	13.5	13.3	14.5
	d) Storm event 16/8/85	14.5	14.0	12.9
COD mg/L	a) Spring runoff 29/4/83	18.5	18.5	17.6
	b) Dry weather 13/9/83	8.7	11	13
	c) Dry weather 28/8/84	34.3	36.3	40.4
	d) Storm event 16/8/85	40.8	37.9	35.1

(iii) Nutrients

Some nutrient levels (TKN, DOC, COD) were higher during storm-event surveys compared with spring-runoff survey and one of the two dry-weather surveys. The second dry-weather survey contained elevated nutrient levels, but the values varied little from station to station.

(iv) Metals

Concentrations of metals at all stations were generally low and no obvious trends were apparent for metals between different types of surveys.

4.3.3 Statistical Analyses

(a) Distance-Decay Model

The results of distance-decay model analyses are given in Table 4.16 for the pooled data, and in Tables 4.17-4.19 for the seasonal data. For the pooled data, decay coefficients (B-values) were significantly ($P \leq 0.05$) negative for HPC35, HPC20, ANA and FUNGI. The TC and FC counts showed no relationship with distance. FS counts showed a slightly increasing trend, probably caused by further downstream contamination.

The coefficient-of-determination (R^2) values were very small (<18%) for all variables except for ANA. This indicates the use of poor-fitting distance-decay equations. The principal cause of this is very low initial loadings of all bacterial counts, ranging from 36 to 4049 in antilog units for the pooled data. If the initial loadings are small, then additional samplings downstream from the impact station will not be able to detect any noticeable trend in variation of microbial counts.

A significant negative relationship between levels of various microbial parameters and distance was evident for seasonal models (Tables 4.17-4.19). However, FC counts in spring-runoff surveys, plus HPC35, HPC20 and FS counts in storm-event surveys, and TC, FC and FS counts in dry-weather surveys were not statistically significant ($P > 0.05$). Initial loadings were generally highest in the spring-runoff survey which also resulted in highest R^2 values. Smaller R^2 values were observed for the dry-weather survey which also had lowest initial loadings of all microbial types.

Based on the levels of various microbial parameters at this feedlot, results indicated that distance-decay models are unsatisfactory to account for the variation in microbial counts. It was also noticed that within a distance of 17 km from the impact station, most microbial counts will reduce to non-detectable levels, assuming no additional pollution inputs and identical conditions in the extrapolated zone as in the sampling zone.

(b) Multiple-Regression Model

Multiple-regression equations based on stepwise techniques are presented in Table 4.20 for the pooled data and in Tables 4.21-4.23 for the seasonal surveys. All regression coefficients reported are highly significant ($P \leq 0.01$).

For the pooled data (Table 4.20), several independent variables were found to have a significant effect on microbial counts. They accounted for most of the variation in these counts with R^2 values ranging from 60-94%. These were DIST, TEMP, TURB, pH and OP. Correlation coefficients between TDS.SCOND, NFR.NO_2+NO_3, NFR.OP, NFR.NO_2, TKN.DOC, TKN.COD, NO_2+NO_3.NO_2, TP.NO_2, DOC.COD

Table 4.16. Logarithmic distance-decay coefficients[a] for all data from Prime Feeders Ltd.

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σ_e	R^2	DISTANCE TO 1 COUNT (km)
LOG HPC 35	212	3.234478 (1715)	-.000180[c]	.000026	44.82	.260510	.1758	17.96
LOG HPC 20	213	3.607410 (4049)	-.000234[c]	.000060	14.82	.590617	.0656	15.41
LOG ANA	216	2.646507 (443)	-.000380[c]	.000030	155.20	.297483	.4203	6.96
LOG FUNGI	216	1.566431 (36)	-.000344[c]	.000065	27.76	.636956	.1148	4.55
LOG TC	108	2.826174 (670)	.000003	.000111	0.00	.7671	.0000	942.05
LOG FC	107	2.249870 (177)	-.000069	.000091	.58	.6250	.0054	32.60
LOG FS	106	2.513261 (326)	.000187[c]	.000094	3.95	.6465	.0365	13.43

[a] Model: LOG Y = LOG A + BD

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] Significant ($P \leq 0.05$)

Table 4.17. Logarithmic distance-decay coefficients[a] for spring-runoff data from Prime Feeders Ltd.

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σe	R^2	DISTANCE TO 1 COUNT (km)
LOG HPC 35	44	3.658908 (4559)	-.000357[c]	.000041	73.92	.1453	.6376	10.24
LOG HPC 20	47	4.716751 (52089)	-.000334[c]	.000037	77.85	.1420	.6336	14.12
LOG ANA	48	2.778092 (599)	-.000197[c]	.000039	25.59	.1468	.3574	14.10
LOG FUNGI	48	2.615480 (412)	-.000600[c]	.000062	92.77	.2338	.6685	4.35
LOG TC	24	3.248412 (1771)	-.000581[c]	.000098	34.81	.2613	.6127	5.59
LOG FS	24	1.883135 (76)	-.000217[c]	.000052	17.40	.1384	.4416	8.67
LOG FC	23	1.981529 (95)	-.000074	.000041	3.16	.1079	.1306	26.77

[a] Model: $LOG\ Y = LOG\ A + BD$

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] Significant ($P \leq 0.05$)

Table 4.18. Logarithmic distance-decay coefficients[a] for storm-event data from Prime Feeders Ltd.

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σ_e	R^2	DISTANCE TO 1 COUNT (km)
LOG HPC 35	60	3.148092 (1406)	-.000016	.000009	2.94	.0530	.0482	196.75
LOG HPC 20	60	3.073609 (1184)	.000014	.000011	1.71	.0629	.0287	--
LOG ANA	60	2.856518 (718)	-.000673[c]	.000033	414.18	.1856	.8771	4.24
LOG FUNGI	60	1.104521 (12)	.000073[c]	.000025	8.49	.1408	.1277	--
LOG TC	30	3.776707 (5980)	-.000073[c]	.000029	6.17	.1167	.1805	51.73
LOG FC	30	3.005269 (1012)	-.000147[c]**	.000023	38.67	.0942	.5800	20.44
LOG FS	30	3.157865 (1438)	.000068	.000033	4.09	.1337	.1273	—

[a] **Model: LOG Y = LOG A + BD**

[b] **Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).**

[c] **Significant ($P \leq 0.05$)**

Table 4.10. Logarithmic distance-decay coefficients[a] for dry-weather data from Prime Feeders Ltd.

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σe	R^2	DISTANCE TO 1 COUNT (km)[b]
LOG HPC 35	108	3.089307 (1228)	-.000203[c]	.000029	47.72	.2029	.3104	15.21
LOG ANA	108	2.426981 (267)	-.000196[c]	.000038	25.86	.2667	.1961	12.38
LOG FUNGI	108	1.261270 (18)	-.000394[c]	.000070	31.62	.4837	.2297	3.20
LOG HPC20	106	3.259172 (1816)	-.000153[c]	.000027	32.01	.1841	.2353	21.30
LOG TC	54	2.227107 (168)	.000103	.000125	.69	.6101	.0130	--
LOG FC	54	2.045764 (111)	-.000152	.000129	1.39	.6291	.0260	13.45
LOG FS	51	2.618379 (415)	.000168	.000108	2.42	.5228	.0460	--

[a] Model: LOG Y = LOG A + BD

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] Significant ($P \leq 0.05$)

and R2D.R3D were all positive and highly significant ($P < 0.01$), with a value of 0.90 or higher. If these pairs of variables occur together in the regression models they may cause multicollinearity problems. However, this was not the case in the present study because none of these pairs of variables appeared together in the model.

Multiple-regression analyses for the seasonal data (Tables 4.21-4.23) also showed that in most cases DIST, TEMP, TURB, SCOND and pH accounted for most of the variation in microbial counts. The R^2 values ranged from 22-97%, but in most cases were above 50%. The seasonal models are based on very small numbers of observations, ranging from 18 to 84. Therefore, these results should be taken as indicative rather than conclusive as they may change with a larger sample size.

In summary, multiple-regression models accounted for most of the variation in microbial counts and were far superior to the distance-decay equations. Independent variables such as DIST, TEMP, TURB, SCOND and pH were found to have a significant influence on microbial counts. Therefore, in any future monitoring programs and feedlot-impact studies, the importance of these variables should be emphasized.

Table 4.20. Multiple-regression equations based on pooled data from Prime Feeders Ltd.

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	0.3495	Intercept	3.0109	Intercept	3.0850	Intercept	13.9834	Intercept	3.6066	Intercept	3.1980	Intercept	1.8566
DIST	-0.0002	DIST	-0.0001	DIST	-0.0001	TURB	-2.2571	DIST	0.0001	FR	-0.0039	DIST	0.0001
TEMP	0.0245	TURB	-0.7818	TEMP	-0.0548	PH	-1.2749	TURB	-0.9491	TP	-7.0793	PH	0.3239
PH	0.2515	NFR	0.0330	OP	17.3707	FR	-0.0039	SCOND	-0.0023	R7D	0.0281	SCOND	-0.0039
NO2	56.5625			NO2NO3	-6.0439	PARTC	0.4058	PARTC	-0.3163			OP	-33.5757
						R7D	0.0241	R7D	0.0257				
N	153	N	156	N	156	N	155	N	78	N	78	N	76
R2	0.6646	R2	0.9383	R2	0.6081	R2	0.9402	R2	0.9109	R2	0.8706	R2	0.9166
M.S.E.	0.0302	M.S.E.	0.0237	M.S.E.	0.0562	M.S.E.	0.0376	M.S.E.	0.0679	M.S.E.	0.0656	M.S.E.	0.0425

Table 4.21. Multiple-regression equations based on spring-runoff data from Prime Feeders Ltd.

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	1.8591	Intercept	2.5947	Intercept	1.1538	Intercept	1.6096	Intercept	-0.6528	NV[*]		NV	
DIST	-0.0001	DIST	-0.0001	DIST	-0.0001	DIST	-0.0004	DIST	-0.0002				
TEMP	0.1624	TEMP	0.1990	TEMP	0.1601	TEMP	0.0948	TEMP	0.3709				
N	33	N	36	N	36	N	35	N	18				
R2	0.5879	R2	0.7909	R2	0.6719	R2	0.8343	R2	0.9621				
M.S.E.	0.0203	M.S.E.	0.0109	M.S.E.	0.0128	M.S.E.	0.0227	M.S.E.	0.0059				

[*] NV: No variable met the $P \leq 0.05$ significance level for entry into the model.

Table 4.22. Multiple-regression equations based on storm-event data from Prime Feeders Ltd.

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	2.5069	Intercept	3.3106	Intercept	-1.0831	NV*		NV		NV		Intercept	1.8459
DIST	-0.0001	DIST	-0.0211	DIST	-0.0011							TEMP	0.1094
TEMP	0.0603			TEMP	0.3498								
N	36	N	36	N	36							N	18
R2	0.2874	R2	0.2210	R2	0.9708							R2	0.8663
M.S.E.	0.0035	M.S.E.	0.0030	M.S.E.	0.0076							M.S.E.	0.0037

*NV: No variable met the $P \leq 0.05$ significance level for entry into the model.

Table 4.23. Multiple-regression equations based on dry-weather data from Prime Feeders Ltd.

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	1.8359	Intercept	2.5624	Intercept	3.2044	Intercept	0.2144	Intercept	25.8353	Intercept	12.8455	Intercept	41.4767
DO2	-0.0666	TURB	-2.3878	TEMP	-0.0912	DIST	0.0003	DIST	0.0005	DIST	0.0009	DIST	0.0007
TURB	-2.5277	SCOND	0.0018	SCOND	0.0009	DO2	-0.3280	PH	-2.4546	DO2	-0.2366	TEMP	0.6731
SCOND	0.0041					TURB	-10.0389	SCOND	-0.0036	TURB	-10.8813	DO2	-0.3175
						SCOND	0.0102			PH	-1.4387	TURB	-14.1979
										SCOND	0.0105	PH	-4.9223
N	84	N	84	N	84	N	84	N	42	N	42	N	40
R2	0.5149	R2	0.3142	R2	0.4839	R2	0.8760	R2	0.8129	R2	0.8168	R2	0.8985
M.S.E.	0.0337	M.S.E.	0.0284	M.S.E.	0.0450	M.S.E.	0.0487	M.S.E.	0.0976	M.S.E.	0.0779	M.S.E.	0.0543

4.4 Wes Yanke Ranch, Medicine Hat

Precipitation in the feedlot vicinity was very sparse during 1983 and 1984, and weather conditions during the spring and summer seasons were very dry. Therefore, three dry-weather surveys were conducted during these years on July 12, 1983, September 27, 1983 and September 18, 1984. Weather conditions during 1985 were more favorable for spring-runoff and storm-event surveys. Two such surveys were conducted on March 26, 1985, following 1.12 cm precipitation in 7 days, and September 13, 1985, following 2.6 cm precipitation within 2 days and 5.4 cm precipitation within 7 days (rain and snow), respectively.

4.4.1 Microbiological Analyses

The GMs (seasonal loadings) of values obtained for each parameter for all surveys conducted during spring-runoff, storm-event or dry-weather conditions are presented in Table 4.24. In addition, the GMs (station loadings) of each parameter per station for individual surveys are presented in Table 4.25. Major findings of surveys conducted at Wes Yanke Ranch are discussed here in terms of seasonal and station loadings according to various parameter groups.

(a) Pollution-Indicator Bacteria

(i) Levels of TC, FC and FS in the creek adjacent to Wes Yanke Ranch were higher during the storm-event survey than during the spring-runoff or dry-weather surveys (Table 4.24). For example, during the storm-event survey, the densities of TC and FC at all stations ranged from 9,200 to 11,000/100 mL and 560 to 1,700/100 mL, respectively. This exceeds the guidelines for Canadian/Alberta

Table 4.24. Seasonal loadings (geometric means) of microbial levels at Wes Yanke Ranch

MICROBIAL PARAMETER		SURVEY TYPE	STATION				
			PRE-IMPACT	IMPACT		INFLUENCE	POST-IMPACT
			1	2	3	4	5
TOTAL COLIFORMS per 100 mL		a) Spring runoff	120^{c}	180^{a}	150^{b}	190^{a}	$160^{b,c}$
		b) Storm event	9200^{b}	11000^{a}	9200^{b}	9100^{b}	$10000^{a,b}$
		c) Dry weather	$1700^{a,b}$	$1700^{a,b}$	1900^{a}	1200^{b}	$1700^{a,b}$
FECAL COLIFORMS per 100 mL		a) Spring runoff	2^{a}	81^{d}	3^{b}	13^{c}	1^{a}
		b) Storm event	560^{c}	780^{b}	1800^{a}	700^{b}	1700^{a}
		c) Dry weather	530^{a}	450^{a}	330^{a}	190^{b}	120^{b}
FECAL STREPTOCOCCI per 100 mL		a) Spring runoff	140^{d}	350^{b}	290^{c}	$310^{b,c}$	630^{a}
		b) Storm event	690^{d}	1600^{c}	3200^{b}	1500^{c}	5800^{a}
		c) Dry weather	1500^{a}	1600^{a}	1400^{a}	390^{b}	290^{b}
HETEROTROPHS (AEROBIC) per mL	20°C	a) Spring runoff	86000^{b}	100000^{a}	77000^{b}	64000^{c}	48000^{d}
		b) Storm event	6800^{c}	8400^{b}	10000^{a}	8200^{b}	8300^{b}
		c) Dry weather	13000^{b}	11000^{c}	16000^{a}	13000^{b}	10000^{c}
	35°C	a) Spring runoff	1900^{b}	5000^{a}	5000^{a}	1500^{c}	900^{d}
		b) Storm event	5100^{c}	6400^{b}	7400^{a}	5300^{c}	6500^{b}
		c) Dry weather	$7000^{a,b}$	6000^{b}	8300^{a}	$5900^{b,c}$	5100^{c}
ANAEROBES per mL		a) Spring runoff	540^{a}	540^{a}	440^{b}	560^{a}	$510^{a,b}$
		b) Storm event	1300^{b}	1200^{a}	1800^{d}	1200^{a}	1500^{c}
		c) Dry weather	1100^{b}	1000^{b}	1000^{b}	860^{c}	1800^{a}
TOTAL FUNGI (Yeast & Molds) per mL		a) Spring runoff	73^{c}	86^{b}	91^{b}	100^{a}	74^{c}
		b) Storm event	53^{d}	67^{b}	84^{c}	66^{b}	100^{a}
		c) Dry weather	17^{c}	$20^{b,c}$	28^{a}	21^{b}	$22^{a,b}$

^{a,b,c,d} Station means with same superscript are not significantly different at $P < 0.05$.

Table 4.25. Station loadings (geometric means) of microbial levels at Wes Yanke Ranch

MICROBIAL PARAMETER	SURVEY TYPE	STATION				
		PRE-IMPACT	IMPACT		INFLUENCE	POST-IMPACT
		1	2	3	4	5
TOTAL COLIFORMS per 100 mL	Spring runoff 03/26/85	120^{c}	180^{a}	150^{b}	190^{a}	$160^{b,c}$
	Summer Storm 13/09/85	9200^{b}	11000^{a}	9200^{b}	9100^{b}	$10000^{a,b}$
	Dry Weather 12/07/83	1600^{a}	1100^{b}	1800^{a}	680^{c}	--
	Dry weather 27/09/83	1800^{b}	4000^{a}	$2700^{a,b}$	$2300^{a,b}$	$2500^{a,b}$
	Dry weather 18/09/84	1600^{a}	1100^{b}	$1300^{a,b}$	1100^{b}	1100^{b}
FECAL COLIFORMS per 100 mL	Spring runoff 03/26/85	2^{a}	81^{d}	3^{b}	13^{c}	1^{a}
	Summer Storm 13/09/85	560^{c}	780^{b}	1800^{a}	700^{b}	1700^{a}
	Dry Weather 12/07/83	1300^{a}	$680^{a,b}$	510^{b}	400^{b}	--
	Dry Weather 27/09/83	470^{a}	300^{b}	230^{b}	40^{d}	110^{c}
	Dry weather 18/09/84	260^{b}	440^{a}	300^{b}	410^{a}	120^{c}
FECAL STREPTOCOCCI per 100 mL	Spring runoff 03/26/85	140^{d}	350^{b}	290^{c}	$300^{b,c}$	630^{a}
	Summer Storm 13/09/85	690^{d}	1600^{c}	3200^{b}	1500^{c}	5800^{a}
	Dry Weather 12/07/83	1500^{a}	1200^{b}	1000^{a}	470^{c}	--
	Dry Weather 27/09/83	$7000^{a,b}$	8400^{a}	5000^{b}	300^{c}	420^{c}
	Dry weather 18/09/84	1600^{a}	1100^{b}	$1300^{a,b}$	1100^{b}	1100^{b}

Table 4.25 (cont'd). Station loadings (geometric means) of microbial levels at Wes Yanke Ranch

MICROBIAL PARAMETER	SURVEY TYPE	STATION				
		PRE-IMPACT	IMPACT		INFLUENCE	POST-IMPACT
		1	2	3	4	5
HETEROTROPHS AEROBICS per mL 20°C	Spring runoff 03/26/85	86000^{b}	100000^{a}	77000^{b}	64000^{c}	48000^{d}
	Summer Storm 13/09/85	6800^{c}	8400^{b}	10000^{a}	8200^{b}	8300^{b}
	Dry Weather 12/07/83	16000^{a}	14000^{a}	17000^{a}	14000^{a}	
	Dry weather 27/09/83	13000^{b}	8500^{d}	19000^{a}	12000^{b,c}	11000^{c}
	Dry weather 18/09/84	11000^{a}	10000^{a}	12000^{a}	12000^{a}	12000^{a}
35°C	Spring runoff 03/26/85	1900^{b}	5000^{a}	5000^{a}	1500^{c}	900^{d}
	Summer Storm 13/09/85	5100^{c}	6400^{b}	7400^{a}	5300^{c}	6500^{b}
	Dry Weather 12/07/83	8000^{a}	8800^{a}	7800^{a}	6000^{b}	
	Dry Weather 27/09/83	5300^{b}	3800^{c}	9100^{a}	4200^{b,c}	5000^{b,c}
	Dry weather 18/09/84	8700^{a}	6600^{b}	8000^{b}	8000^{b}	7300^{b}
ANAEROBES per mL	Spring runoff 03/26/85	540^{a}	540^{a}	440^{b}	560^{b}	500^{a,b}
	Summer Storm 13/09/85	1300^{b}	1200^{a}	1800^{d}	1200^{a}	1500^{c}
	Dry Weather 12/07/83	1100^{a}	980^{a,b}	940^{a,b}	870^{b}	
	Dry Weather 27/09/83	1200^{a,b}	1100^{b}	1300^{a}	890^{c}	1300^{a}
	Dry weather 18/09/84	960^{b}	960^{b}	860^{c}	830^{c}	3200^{a}
TOTAL FUNGI (Yeast and Molds) per mL	Spring runoff 03/26/85	73^{c}	86^{b}	91^{b}	100^{a}	74^{c}
	Summer Storm 13/09/85	53^{d}	67^{b}	84^{c}	66^{b}	100^{a}
	Dry Weather 12/07/83	<30	<30	<30	<30	
	Dry Weather 27/09/83	10^{d}	15^{c}	54^{a}	10^{d}	27^{b}
	Dry weather 18/09/84	16^{b}	17^{b}	15^{b}	31^{a}	17^{b}

^{a,b,c,d} Station means with same superscript within a survey are not significantly different at $P < 0.05$.

recreational water quality (2, 6). Despite elevated counts at all stations, some impact of feedlot runoff could be seen. For example, levels of TC at Station 2 (11,000/100mL) were significantly higher than at Station 1 (9,200/100 mL). Similarly, levels of FC and FS were significantly higher at Station 2 (780/100mL and 1,600/100 mL, respectively) and Station 3 (1,800 and 3,200/100 mL) than at Station 1 (560/100mL and 690/100 mL) (Table 4.25).

(ii) The GMs of TC and FC counts observed at all stations during the dry-weather surveys also exceeded the guidelines for Canadian/Alberta recreational water quality (2, 6), (Table 4.24).

(iii) Little or no impact in levels of TC, FC and FS was observed during the dry-weather surveys. Nonetheless, FC counts during the Sept. 18, 1984 survey were significantly higher at Station 2 (440/100 mL) than at Station 1 (260/100 mL) (Table 4.25). This trend was not reflected in the TC or FS counts.

(iv) Levels of PIB were much lower during spring-runoff conditions than during the other types of surveys. For instance, TC levels ranged from 120 to 190/100 mL, while FC levels ranged from 1 to 81/100 mL (Table 4.25). A small, but notable, effect of the feedlot on the water quality of the creek was observed at Station 2 where the FC count (81/100 mL) was significantly higher than the count at pre-impact Station 1 (2/100 mL) during the spring-runoff survey done on March 26, 1985.

(b) Heterotrophic Bacteria

(i) Heterotrophic bacterial populations in general were not greatly elevated during all types of surveys. Aerobic heterotrophic

(20°C) counts were generally higher, however, during the spring-runoff survey than during storm-event or dry-weather surveys (Table 4.24). In contrast, levels of anaerobic heterotrophs were roughly one-half of those observed during storm-event or dry-weather surveys.

(ii) Some impact of the feedlot was observed during the spring survey when aerobic heterotrophic bacteria (20°C, 35°C) were found to be significantly higher at Station 2 (100,000 and 5,000/mL, respectively) and Station 3 (77,000 and 5000/mL, respectively) than at Station 1 (86,000 and 1,900/mL, respectively) (Table 4.25).

(iii) No strong evidence of feedlot impact was reflected in densities of heterotrophic bacteria during summer-storm or dry-weather surveys. Their levels were significantly higher, however, at Station 3 than at other stations during the dry-weather survey conducted September 27, 1983 (Table 4.25). This indicated some feedlot impact.

(c) Total Fungi (Yeasts and Molds)

(i) Densities of total fungi were generally low ($\leq$100 CFU/mL) during all surveys (Table 4.25). Although the lowest counts were observed during the dry-weather surveys, a small, but obvious, impact occurred at Station 3 (54 CFU/mL), where counts were significantly higher than those recorded at stations located upstream or downstream of the feedlot.

4.4.2 Physical and Chemical Analyses

All the raw data obtained for physical and chemical parameters from each survey conducted at Wes Yanke Ranch are presented in the unpublished data appendix.

Table 4.26. Seasonal loadings of chemical levels at Wes Yanke Ranch

CHEMICAL PARAMETER	SURVEY DATE	STATION PRE-IMPACT 1	STATION IMPACT 2	STATION IMPACT 3	STATION INFLUENCE 4
TDS mg/L	a) Dry weather 12/7/83	381	–	368	429
	b) Dry weather 27/9/83	1687	1567	780	695
	c) Dry weather 18/9/84	240	243	251	238
	d) Storm event 13/9/85	300	308	310	323
	e) Spring runoff 26/3/85	810	698	652	687
NFR mg/L	a) Dry weather 12/7/83	7	6	4	4
	b) Dry weather 27/9/83	26	12	29	22
	c) Dry weather 18/9/84	13	11	19	19
	d) Storm event 13/9/85	36	19	22	18
	e) Spring runoff 26/3/85	19	20	19	14
S. COND. µS/cm	a) Dry weather 12/7/83	621	616	607	702
	b) Dry weather 27/9/83	2310	2200	1224	1097
	c) Dry weather 18/9/84	415	419	436	422
	d) Storm event 13/9/85	531	534	546	552
	e) Spring runoff 26/3/85	1221	1043	976	1070
TKN mg/L as N	a) Dry weather 12/7/83	0.68	0.86	0.84	0.86
	b) Dry weather 27/9/83	0.80	0.78	1.2	1.2
	c) Dry weather 18/9/84	0.92	0.90	0.85	0.88
	d) Storm event 13/9/85	0.88	0.86	0.92	0.90
	e) Spring runoff 26/3/85	1.48	1.54	1.60	1.76
DOC mg/L as C	a) Dry weather 12/7/83	8.0	8.1	8.5	8.6
	b) Dry weather 27/9/83	10	9.5	11	10
	c) Dry weather 18/9/84	5.4	4.6	4.4	4.8
	d) Storm event 13/9/85	2.5	4.2	4.5	4.5
	e) Spring runoff 26/3/85	12.3	12.6	12.6	12.6
COD mg/L	a) Dry weather 12/7/83	25.1	22.2	23.3	21.4
	b) Dry weather 27/9/83	25.8	44.5	106	38.6
	c) Dry weather 18/9/84	19.9	17.9	18.9	22.7
	d) Storm event 13/9/85	22.7	19.8	18.8	18.8
	e) Spring runoff 26/3/85	37.7	40.7	41.7	40.7

Some selected data for these surveys, indicating seasonal loadings, are presented in Table 4.26. Major findings with regard to station loadings within individual surveys, as well as seasonal loading variations, are discussed here.

(a) Station Loadings

(i) Physical Parameters

The surface waters were moderate in pH (8.0-8.7 pH), moderately high in specific conductance (415-2310 µs/cm) and moderately low in suspended solids (4-36 mg/L). The data indicated very little variation between stations and no input from the feedlot, with the exception of the September, 1983 dry-weather event, where the specific conductance dropped from 2310 µs/cm at Station 1 to 1097 µs/cm at Station 4.

(ii) Major Ions

There were significant levels of Ca, Mg, Na, $SO_4^=$, and HCO_3^- (T.ALK) ions present at all stations. Concentrations of these ions were nearly constant at all stations, with the exception of the September, 1983 event where the concentration of most major ions dropped from Station 2 to Station 3. Little or no input was evident from the feedlot, however.

(iii) Nutrients

Moderate to low concentrations of TKN (0.78-1.76 mg/L), NH_3-N (0.007-0.551) and TP (0.052-0.183) were observed in surface-waters. Little or no input was evident from the feedlot, however.

(iv) Metals

Metal concentrations at all stations were very low; only Fe, Mn, and Al were above detectable levels. No input from the feedlot was evident for any metal.

(b) Seasonal Loadings

(i) Physical Parameters

The pH levels were marginally higher (pH 8.6) during one dry-weather event, compared with the other events (7.9-8.3 pH). The specific conductance of the dry-weather events varied so significantly that no obvious trends could be identified when compared with spring-runoff and storm-events. The spring-runoff specific conductance, however, was generally higher than the storm-event levels. The NFR levels were essentially constant between events.

(ii) Major Ions

The major ion concentrations increased proportionately with the increase in the specific conductance during dry-weather events, but later showed highly variable results. The spring-runoff levels of major ions were generally higher than the storm-event levels.

(iii) Nutrients

The TKN, DOC, and COD levels were generally higher for the spring-runoff event compared with the dry-weather and storm-events. The dry-weather values varied somewhat between the two surveys.

(iv) Metals

The spring-runoff event produced higher Al, Fe, and Mn levels than the other events. The observed detection level concentrations, however, indicated that the feedlot was not contributing heavy metals to the watercourse.

4.4.3 Statistical Analyses

(a) Distance-Decay Model

The results of distance-decay model analyses are presented in Table 4.27 for the pooled data, and for the seasonal data in Tables 4.28-4.30. There was a significant ($P \leq 0.05$) negative relationship between distance and HPC35, FC and FS counts in the pooled data. A significant positive relationship was noted for ANA. No significant ($P > 0.05$) relationship was noted between distance and HPC20, FUNGI and TC. The coefficient-of-determination (R^2) values accounted for by the distance alone were quite low, ranging from 0 to 11%. This indicated the inability of the distance-decay model to explain the variability in microbial counts.

Distance-decay models, based on the seasonal data (Tables 4.28-4.30), showed a significant ($P \leq 0.05$) negative relationship between distance and HPC35, HPC20, FUNGI and FC for the spring-runoff survey, and between distance and HPC35, HPC20, FC and FS for the dry-weather survey. The R^2 values for the spring-runoff survey were quite high, up to 72% for HPC35. For the storm-event and dry-weather surveys, however, R^2 values were mostly low, indicating poor-fitting distance-decay equations. Significant positive relationships were noted between FS and distance for the spring runoff, between ANA and distance for the dry-weather conditions and between FUNGI, FC, FS and distance for the storm-event surveys. This indicates that additional microbial contamination was occurring in the post-impact sampling zone from some undefined sources.

Table 4.27. Logarithmic distance-decay coefficients[a] for all data from Wes Yanke Ranch

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σe	R^2	DISTANCE TO 1 COUNT (km)
LOG HPC 35	232	3.819648 (6601)	-.000094[c]	.000017	28.66	.262326	.1107	40.63
LOG HPC20	229	4.256420 (18047)	-.000034	.000023	2.15	.352931	.0093	125.18
LOG ANA	229	2.937997 (867)	.000050[c]	.000013	13.38	.202470	.0556	--
LOG FUNGI	231	1.563396 (36)	.000023	.000022	1.10	.330729	.0047	--
LOG TC	116	3.175216 (1496)	-.000014	.000058	.06	.612880	.0005	226.80
LOG FC	116	2.482916 (304)	-.000231[c]	.000077	8.81	.820457	.0717	10.74
LOG FS	116	3.040661 (1098)	-.000101[c]	.000045	5.02	.478983	.0421	30.10

[a] Model: LOG Y = LOG A + BD

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] Significant ($P \leq 0.05$)

Table 4.28. Logarithmic distance-decay coefficients[a] for spring-runoff data from Wes Yanke Ranch

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σe	R^2	DISTANCE TO 1 COUNT (km)[b]
LOG HPC 35	48	3.730311 (5374)	-.000297[c]	.000027	119.58	.1890	.7221	12.55
LOG HPC20	48	4.980714 (95656)	-.000115[c]	.000013	78.64	.0905	.6309	43.31
LOG FUNGI	48	1.972878 (94)	-.000026[c]	.000011	5.93	.0765	.1141	75.87
LOG ANA	46	2.713860 (517)	-.000002	.000012	.03	.0887	.0007	1356.93
LOG TC	24	2.233840 (171)	-.000013	.000032	.17	.1583	.0076	171.83
LOG FC	24	1.560476 (36)	-.000556[c]	.000094	34.56	.4654	.6110	2.80
LOG FS	24	2.447576 (280)	.000106[c]	.000020	27.38	.0999	.5544	--

[a] Model: LOG Y = LOG A + BD

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] Significant ($P \leq 0.05$)

Table 4.29. Logarithmic distance-decay coefficients[a] for storm-event data from Wes Yanke Ranch

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σe	R^2	DISTANCE TO 1 COUNT (km)[b]
LOG HPC 35	48	3.810087 (6457)	-.000005	.000011	.19	.0816	.0041	762.01
LOG HPC20	48	3.949890 (8910)	-.000009	.000010	.84	.0721	.0180	438.87
LOG ANA	48	3.114828 (1302)	.000024	.000012	4.02	.0841	.0804	--
LOG FUNGI	48	1.824338 (66)	.000061[c]	.000011	28.34	.0804	.3812	--
LOG TC	24	3.989978 (9771)	-.000002	.000014	.04	.0728	.0017	1994.98
LOG FC	24	2.944927 (880)	.000094[c]	.000035	6.87	.1768	.2379	--
LOG FS	24	3.206569 (1609)	.000179[c]	.000033	28.03	.1668	.5602	--

[a] Model: LOG Y = LOG A + BD

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] Significant ($P \leq 0.05$)

Table 4.30. Logarithmic distance-decay coefficients[a] for dry-weather data from Wes Yanke Ranch

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σe	R^2	DISTANCE TO 1 COUNT (km)[b]
LOG HPC 35	136	3.844942 (6997)	-.000041[c]	.000016	6.24	.1868	.0445	93.77
LOG HPC20	133	4.117702 (13112)	-.000024[c]	.000012	4.01	.1358	.0297	171.57
LOG ANA	135	2.942608 (876)	.000088[c]	.000014	39.46	.1552	.2288	--
LOG FUNGI	135	1.349476 (22)	.000005	.000019	.07	.2210	.0005	--
LOG TC	68	3.215677 (1643)	-.000015	.000032	.21	.2573	.0031	214.37
LOG FC	68	2.627812 (424)	-.000215[c]	.000039	29.15	.3145	.3063	12.22
LOG FS	68	3.200130 (1585)	-.000297[c]	.000051	33.12	.4077	.3341	10.77

[a] Model: LOG Y = LOG A + BD

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] Significant ($P \leq 0.05$)

In summary, it was noticed that distance-decay equations were not able to predict the fate of microbial counts at an acceptable level of confidence. This is probably caused by very low initial loadings of microbes at the impact stations. Therefore, in situations such as this, the distance-decay model may be unsatisfactory for determining the fate of microorganisms during downstream transport.

(b) Multiple-Regression Analysis

Multiple-regression equations, based on the stepwise technique for the pooled data, are presented in Table 4.31, and for the seasonal data in Tables 4.32-4.34. All independent variables listed in these equations were found to be statistically significant at $P \leq 0.01$. For the pooled data, several independent variables were found to have a highly significant effect on the microbial counts. The coefficient-of-determination (R^2) values were quite high, 71.5-95.6%. This indicated that independent variables in the regression equation accounted for most of the variation in microbial counts. TEMP, TURB, pH and SCOND were the most frequently occurring independent variables. There were several pairs of correlation coefficients that were significantly higher ($P \leq 0.05$) than 0.90 in the pooled data. Specifically, correlation coefficients between FR.SCOND, TDS.SCOND, FR.TDS, PARTN.PARTC, TKN.NO_2+NO_3, TKN,NH_3, TKN.NO_2, NH_3.NO_2+NO_3, NO_2.NO_2+NO_3, NH_3.NO_2, OP.DOC, R2D.R3D, R2D.R7D and R3D.R7D were all positive and higher than 0.90. Occurrence of these pairs of variables in the regression model may cause multicollinearity resulting from high correlation coefficients. This was noticed for

Table 4.31. Multiple-regression equations based on pooled data from Wes Yanke Ranch

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	8.0910	Intercept	4.2193	Intercept	3.2732	Intercept	1.4546	Intercept	5.4154	Intercept	4.4848	Intercept	13.2218
DIST	-0.0000	DO2	-0.0268	TKN	-0.2729	TURB	-4.0031	PH	-0.2879	TKN	-2.3696	TEMP	0.1196
TEMP	0.0928	NFR	0.0048	R3D	0.0255	TD	1.7892	SCOND	0.0002	R7D	0.0105	TURB	-7.2068
PH	-0.6820	PARTN	-0.9136	R7D	-0.0103	BOD	0.0457	NO2	-76.7791			PH	-1.4153
		NH3	-0.6739			NO2	-58.5978	R2D	0.0304			SCOND	0.0013
		BOD	0.0847			NO2NO3	10.8329					FR	-0.0007
		NO2	-76.6898									BOD	-0.1450
		NO2NO3	16.4163										
N	202	N	203	N	201	N	204	N	102	N	102	N	102
R2	0.7148	R2	0.9566	R2	0.7881	R2	0.9199	R2	0.9448	R2	0.8007	R2	0.8890
M.S.E.	0.0243	M.S.E.	0.0071	M.S.E.	0.0068	M.S.E.	0.0097	M.S.E.	0.0274	M.S.E.	0.2103	M.S.E.	0.0287

Table 4.32. Multiple-regression equations based on spring-runoff data from Wes Yanke Ranch

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	1.5783	Intercept	6.0418	NV[*]		Intercept	-0.1182	NV		Intercept	7.1060	Intercept	5.4239
TEMP	0.3731	TEMP	0.0845			DIST	-0.0000			DIST	0.0002	DIST	0.0002
DO2	-0.2523	DO2	-0.3510			TEMP	-0.0672			DO2	-2.3590	TEMP	0.1314
TURB	22.3217	TURB	21.8797			DO2	0.3220			TURB	181.1175	DO2	-0.7332
						TURB	-13.0552					TURB	42.5095
N	60	N	60			N	60			N	30	N	30
R2	0.8544	R2	0.6008			R2	0.4388			R2	0.8775	R2	0.9342
M.S.E.	0.0158	M.S.E.	0.0085			M.S.E.	0.0040			M.S.E.	0.0703	M.S.E.	0.0037

[*] NV: No variable met the $P \leq 0.05$ significance level for entry into the model.

Table 4.33. Multiple-regression equations based on dry-weather data from Wes Yanke Ranch

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	3.6292	Intercept	-1.8157	Intercept	2.9581	Intercept	1.7255	Intercept	11.5983	Intercept	3.1282	Intercept	6.7801
DIST	-0.0000	DIST	-0.0000	DIST	-0.0000	TURB	-3.2652	TEMP	-0.3175	DIST	-0.0002	DIST	-0.0001
DO2	-0.0869	DO2	-0.0717	FR	0.0000	SCOND	-0.0001	DO2	-0.1976	SCOND	-0.0002	TEMP	-0.1201
PH	0.1087	TURB	4.2595					TURB	-15.2152	PARTN	-2.4650	DO2	-0.1528
		PH	0.7207					SCOND	0.0027			TURB	-11.3374
		TDS	0.0001					FR	-0.0038			SCOND	0.0005
N	94	N	95	N	96	N	96	N	48	N	48	N	48
R2	0.5505	R2	0.6503	R2	0.3115	R2	0.7753	R2	0.6271	R2	0.8373	R2	0.9803
M.S.E.	0.0142	M.S.E.	0.0048	M.S.E.	0.0045	M.S.E.	0.0119	M.S.E.	0.0284	M.S.E.	0.0352	M.S.E.	0.0061

Table 4.34. Multiple-regression equations based on storm-event data from Wes Yanke Ranch

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	-11.1898	Intercept	-5.8859	Intercept	-5.9763	Intercept	-9.3832	NV*		Intercept	5.5923	Intercept	6.9580
DIST	0.0001	DIST	0.0001	DIST	0.0000	DIST	0.0001			DO2	-0.2637	DO2	-0.3214
TEMP	1.0602	TEMP	0.6918	TEMP	0.6171	TEMP	0.7899			TURB	86.2106	TURB	50.8455
TURB	32.0669	TURB	23.9960	TURB	58.2840	TURB	28.7988						
N	48	N	48	N	48	N	48			N	24	N	24
R2	0.5203	R2	0.4374	R2	0.8244	R2	0.5455			R2	0.8967	R2	0.9359
M.S.E.	0.0043	M.S.E.	0.0048	M.S.E.	0.0013	M.S.E.	0.0043			M.S.E.	0.0046	M.S.E.	0.0043

*NV: No variable met the $P \leq 0.05$ significance level for entry into the model.

the HPC20, with NO_2, NO_2+NO_3 and NH_3 in the model. Similarly, for ANA, FUNGI and FS, minor multicollinearity problems were evident.

Multiple-regression analyses for the seasonal data (Tables 4.32-4.34) also identified important independent variables having an effect on the microbial counts. In general, TEMP, DO_2, TURB and DIST were found to occur most frequently in the regression equations. The R^2 values for the seasonal models were quite high in most cases. These ranged from 43 to 93% for the spring-runoff and storm-event surveys, and 31 to 98% for the dry-weather surveys.

In summary, a large amount of variation in the microbial counts at Wes Yanke Ranch could be accounted for by the independent variables monitored in this study. The R^2 values of regression equations were much better in this regard than those of the distance-decay model. Overall, TEMP, TURB, pH, SCOND, and DO_2 appeared most frequently in the regression equations and affected appreciably the levels of various microbial parameters. Therefore, in any future monitoring programs and feedlot-impact studies, these variables should be emphasized.

4.5 Adams Ranch Ltd., Czar

Six surveys were conducted at Adams Ranch Ltd. Two spring-runoff surveys were conducted on: (1) April 19, 1983, after the watercourse (creek in culvert) had thawed and was flowing towards Ribstone Creek; and (2) April 9, 1985 following a snowfall in which 16.0 mm of precipitation within a 5-day period was recorded. In addition, two storm-event surveys were conducted on: (1) June 19, 1983, after the first continuous rainfall in which 5 cm of precipitation within a 24 h period was recorded; and (2) June 7, 1984, following a major storm event in which 48 mm of precipitation over a 2.5-day period was recorded before sampling was carried out. Two dry-weather surveys were conducted on: (1) October 4, 1983, following a very dry summer season; and (2) October 1, 1984, after a dry summer which was briefly interrupted by a light snowfall (5.2 mm precipitation) 8 days before sampling.

4.5.1 Microbiological Analyses

The GMs (seasonal loadings) of values obtained for each parameter for surveys conducted during spring-runoff, storm-event and dry-weather conditions are presented in Table 4.35. In addition, the GMs (station loadings) of each parameter per station for individual surveys are shown in Table 4.36. Major findings of these surveys are discussed here in terms of seasonal and station loadings according to various parameter groups.

(a) Pollution-Indicator Bacteria

(i) Levels of TC, FC and FS were higher during the storm-event surveys than during the spring-runoff and dry-weather surveys.

Table 4.35. Seasonal loadings (geometric means) of microbial levels at Adams Ranch Ltd.

MICROBIAL PARAMETER		SURVEY TYPE	STATION PRE-IMPACT 1	 IMPACT 2	 INFLUENCE 3	 4	 PRE-IMPACT 5	 POST-IMPACT 6
TOTAL COLIFORMS per 100 mL		a) Spring runoff	42^{c}	1800^{a}	66^{c}	520^{a}	380^{b}	38^{c}
		b) Storm event	1500^{c}	14000^{a}	710^{c}	220^{d}	3300^{b}	650^{c,d}
		c) Dry weather	350^{c}	18000^{a}	38^{d}	140^{c,d}	230^{c}	1500^{b}
FECAL COLIFORMS per 100 mL		a) Spring runoff	2^{d}	340^{a}	19^{b}	32^{b}	16^{c}	3^{d}
		b) Storm event	210^{c,d}	12000^{a}	72^{d}	28^{d}	980^{b}	280^{c}
		c) Dry weather	23^{c,d}	10000^{a}	7^{d}	19^{c,d}	86^{c}	770^{b}
FECAL STREPTOCOCCI per 100 mL		a) Spring runoff	85^{c}	550^{a}	380^{b}	390^{b}	700^{a}	88^{c}
		b) Storm event	4500^{b}	12000^{a}	380^{d}	71^{e}	1400^{c}	340^{d}
		c) Dry weather	290^{b}	30000^{a}	79^{c}	250^{b}	220^{b,c}	280^{b}
HETEROTROPHS (AEROBIC) per mL	20°C	a) Spring runoff	46000^{f}	2000000^{a}	260000^{c}	1370000^{b}	160000^{d}	100000^{e}
		b) Storm event	85000^{b}	310000^{a}	25000^{c}	2000^{e}	26000^{c}	4600^{d}
		c) Dry weather	27000^{b}	140000^{a}	3400^{d}	6100^{d}	14000^{c}	13000^{c}
	35°C	a) Spring runoff	1400^{f}	280000^{a}	20000^{c}	85000^{b}	17000^{d}	6700^{e}
		b) Storm event	41000^{b}	350000^{a}	13000^{d}	1100^{e}	20000^{c,d}	7000^{d}
		c) Dry weather	14000^{b}	150000^{a}	5600^{d}	2600^{d}	13000^{c}	15000^{b}
ANAEROBES per mL		a) Spring runoff	130^{d}	29000^{a}	3000^{e}	7500^{b}	30^{e}	30^{e}
		b) Storm event	4100^{b}	12000^{a}	550^{c}	140^{d}	2100^{b}	290^{c,d}
		c) Dry weather	5500^{b}	46000^{a}	1200^{c}	650^{c}	680^{c}	950^{c}
TOTAL FUNGI (Yeast & Molds) per mL		a) Spring runoff	83^{e}	1000^{a}	430^{d}	490^{c,d}	620^{b,c}	100^{e}
		b) Storm event	1500^{a}	200^{b}	89^{c}	18^{e}	170^{b,c}	40^{d}
		c) Dry weather	78^{a}	92^{a}	10^{c}	13^{c}	33^{b}	34^{b}

^{a,b,c,d,e,f} Stations means with same superscript are not significantly different at $P < 0.05$.

Table 4.36. Seasonal loadings (geometric means) of microbial levels at Adams Ranch Ltd.

MICROBIAL PARAMETER	SURVEY TYPE	STATION					
		PRE-IMPACT	IMPACT	INFLUENCE		PRE-IMPACT	POST-IMPACT
		1	2	3	4	5	6
TOTAL COLIFORMS per 100 mL	Spring runoff 19/04/83	7^{c}	130^{a}	5^{c}	70^{a,b}	36^{b}	11^{c}
	Spring runoff 09/04/85	260^{d}	26000^{a}	800^{c}	4000^{d}	4100^{d}	130^{c}
	Storm event 19/06/83	1100^{d}	180000^{a}	11000^{b}	1000^{d}	13000^{b}	5500^{c}
	Storm event 07/06/84	1600^{b}	5800^{a}	280^{c}	130^{d}	2100^{b}	320^{c}
	Dry weather 04/10/83	1500^{a}	900^{a}	120^{b}	5^{c}	210^{b}	1100^{a}
	Dry weather 01/10/84	82^{e}	370000^{a}	300^{c}	170^{d}	250^{c}	2100^{b}
FECAL COLIFORMS per 100 mL	Spring runoff 19/04/83	3^{c}	150^{a}	6^{b}	3^{c}	0^{d}	0
	Spring runoff 09/04/85	1^{e}	750^{a}	60^{c}	310^{b}	240^{b}	11^{d}
	Storm event 19/06/83	720^{d}	170000^{a}	170^{c}	170^{e}	1500^{c}	3000^{b}
	Storm event 07/06/84	140^{c}	5200^{a}	55^{d}	15^{e}	840^{b}	130^{c}
	Dry Weather 04/10/83	22^{c,d}	290^{b}	9^{d}	2^{e}	48^{c}	890^{a}
	Dry weather 01/10/84	23^{e}	350000^{a}	30^{d,e}	38^{d}	150^{c}	670^{b}
FECAL STREPTOCOCCI per 100 mL	Spring runoff 19/04/83	4^{c}	55^{a}	36^{a}	41^{a}	19^{b}	13^{b}
	Spring runoff 09/04/85	1600^{d}	5600^{b}	4000^{c}	3700^{c}	25000^{a}	590^{e}
	Storm event 19/06/83	20000^{b}	85000^{a}	790^{e}	310^{e}	3400^{c}	2300^{d}
	Storm event 07/06/84	2800^{b}	6400^{a}	300^{d}	44^{f}	1000^{c}	180^{e}
	Dry Weather 04/10/83	300^{c}	2200^{a}	1200^{b}	50^{e}	250^{d}	460^{c,d}
	Dry weather 01/10/84	290^{b}	400000^{a}	120^{d}	52^{e}	200^{c}	170^{c,d}

Table 4.36 (cont'd). Seasonal loadings (geometric means) of microbial levels at Adams Ranch Ltd.

MICROBIAL PARAMETER		SURVEY TYPE	STATION					
			PRE-IMPACT	IMPACT	INFLUENCE		PRE-IMPACT	POST-IMPACT
			1	2	3	4	5	6
HETEROTROPHS AEROBICS per mL	20°C	Spring runoff 19/04/83	66000^{f}	2300000^{a}	480000^{c}	1100000^{b}	140000^{d}	83000^{e}
		Spring runoff 09/04/85	32000^{b}	1790000^{a}	140000^{d}	1800000^{a}	190000^{c}	120000^{d}
		Storm event 19/06/83	2100000^{a}	980000^{b}	74000^{c}	15000^{e}	78000^{c}	49000^{d}
		Storm event 07/06/84	29000^{b}	210000^{a}	18000^{c}	1000^{e}	18000^{c}	1900^{d}
		Dry weather 04/10/83	15000^{b}	10000^{d}	16000^{b}	1100^{d}	39000^{a}	13000^{c}
		Dry weather 01/10/84	49000^{b}	1600000^{a}	9200^{d}	2300^{f}	4700^{e}	13000^{c}
	35°C	Spring runoff 19/04/83	730^{f}	140000^{a}	21000^{c}	72000^{b}	9100^{d}	5600^{e}
		Spring runoff 09/04/85	2100^{f}	540000^{a}	20000^{d}	100000^{b}	33000^{c}	8000^{e}
		Storm event 19/06/83	680000^{b}	4100000^{a}	23000^{c}	1700^{d}	26000^{c}	28000^{c}
		Storm event 07/06/84	$15000^{b,c}$	160000^{a}	1100 0^{c}	950^{e}	19000^{b}	5000^{d}
		Dry Weather 04/10/83	13000^{a}	$10000^{a,b}$	5000^{e}	550^{d}	$7300^{b,c}$	$7400^{b,c}$
		Dry weather 01/10/84	16000^{e}	1400000^{a}	73000^{b}	1500^{f}	22000^{d}	31000^{c}
ANAEROBES per mL		Spring runoff 19/04/83	130^{d}	29000^{a}	3000^{c}	7500^{b}	30^{e}	30^{e}
		Spring runoff 09/04/85	—	—	—	—	—	—
		Storm event 19/06/83	50000^{b}	380000^{a}	1200^{d}	390^{e}	3400^{c}	96^{f}
		Storm event 07/06/84	1800^{b}	2500^{a}	420^{c}	100^{d}	1800^{b}	430^{c}
		Dry Weather 04/10/83	4500^{a}	4700^{a}	1100^{b}	430^{c}	$840^{b,c}$	$950^{b,c}$
		Dry weather 01/10/84	6700^{b}	460000^{a}	3400^{c}	370^{f}	540^{e}	950^{d}
TOTAL FUNGI (Yeast and molds) per mL		Spring runoff 19/04/83	44^{c}	330^{b}	$370^{a,b}$	400^{a}	430^{a}	60^{c}
		Spring runoff 09/04/85	160^{d}	1000^{a}	430^{c}	490^{c}	620^{b}	100^{e}
		Storm event 19/06/83	3600^{a}	1100^{b}	370^{e}	99^{f}	920^{c}	540^{d}
		Storm event 07/06/84	1100^{a}	110^{b}	56^{c}	10^{e}	95^{b}	17^{d}
		Dry Weather 04/10/83	42^{a}	25^{b}	20^{b}	1^{d}	27^{b}	14^{c}
		Dry weather 01/10/84	150^{b}	340^{a}	72^{c}	9^{e}	40^{d}	85^{c}

^{a,b,c,d,e,f} Station means with same superscript within a survey are not significantly different at $P < 0.05$.

At Station 2, however, TC and FS counts were highest during dry-weather surveys (Table 4.35). This was mostly caused by high counts obtained during the fall dry-weather survey of October 1, 1984 (Table 4.36), when drainage of the slough (Station 2) towards Ribstone Creek was minimal and a greater accumulation of runoff probably occurred at this station.

(ii) Levels of PIB at all stations were lowest during the spring-runoff surveys (Table 4.35).

(iii) During all surveys, levels of TC, FC and FS were significantly higher at impact Station 2 than at other stations indicating that runoff was accumulating in the slough adjacent to the feedlot (Table 4.36). However, no impact of the feedlot runoff from Station 2 on the water quality of Ribstone Creek was evident during any survey. This was the result of bacterial populations not being significantly higher at Station 3 in comparison to those at Station 5 (Ribstone Creek).

(iv) The guidelines for Canadian/Alberta recreational water quality (2, 6) for both TC and FC populations were often exceeded in Ribstone Creek. For example, during the summer storm-event surveys, TC and FC levels at Station 5 (3,300 and 980/100 mL, respectively) and FC levels at downstream Station 6 (280/100 mL) were above water-quality limits (Table 4.35). Likewise, TC and FC levels at Station 6 (1,500 and 770/100mL, respectively) exceeded the limits during dry-weather surveys.

(b) Heterotrophic Bacteria

(i) The GMs of the densities of aerobic (20°C, 35°C) and anaerobic heterotrophic bacteria were generally higher at Station 2 during spring-runoff surveys in comparison to storm-event and dry-weather surveys (Table 4.35). In addition, during the spring runoff, the GMs of aerobic (20°C, 35°C) and anaerobic heterotrophic bacteria were significantly higher at Station 3 (260,000, 20,000 and 3,000/mL, respectively) than at Station 5 (160,000, 17,000 and 30/mL, respectively) suggesting an overall influence of increased bacterial input through feedlot runoff (Table 4.35).

(ii) When spring-runoff surveys were individually examined, however, such an impact was clear during the April 9, 1985 survey, but was not apparent during the April 19, 1983 survey (Table 4.36). It is difficult to explain this variation, but slightly elevated levels of heterotrophic bacteria at Station 5 may be caused by nearby, unidentified sources.

(c) Total Fungi (Yeasts and Molds)

(i) The GMs of fungal counts observed during all survey types varied greatly (Table 4.35). The highest counts were obtained during the spring-runoff (83 to 1000 CFU/mL) and storm-event (18 to 1500 CFU/mL) surveys, while the lowest counts were obtained during the dry-weather surveys (10 to 92 CFU/mL) .

(ii) Although counts were generally significantly higher at Station 2 than at other stations (Table 4.36), no impact on the fungal densities of Ribstone Creek was observed because levels at Station 3 were significantly lower than those of Station 5.

(iii) Fungal densities at Adams Ranch Ltd. were typically higher than those noted in the receiving waters at other feedlots. This may be related to the slow drainage characteristics of the watercourse at this ranch. In combination with the large contribution of feedlot runoff into the slough adjacent to the feedlot, this would significantly encourage fairly eutrophic conditions.

4.5.2. Physical and Chemical Analyses

All the raw data obtained for physical and chemical parameters from each survey conducted at Adams Ranch Ltd. are presented in the unpublished data appendix. Selected data for these surveys, indicating seasonal loadings, are presented in Table 4.37. Major findings with regard to station loadings within individual surveys, as well as seasonal loading variations, are discussed here.

(a) Station loadings

(i) Physical parameters

The pH in Shorncliffe Lake (Station 1), situated above the drainage area and providing source water to the slough, ranged between pH 7.8-8.4. The specific conductance was highly variable (869-3440 µs/cm). At most times, it was higher than that of the slough and the creek station (372-2570 µs/cm). The NFR levels (11-38 mg/L) were lower at Station 1 as compared to those observed at Station 2 (45-127 mg/L).

The creek, which drains the slough, and Ribstone Creek have similar pH values (7.9-8.9 pH). The suspended solids of these waters were variable, and the specific conductance values were generally lower than those of the slough or the lake. The lowest specific conductance values were consistently found at Station 5.

Table 4.37. Seasonal loadings of chemical levels at Adams Ranch Ltd.

		STATION				
CHEMICAL PARAMETER	SURVEY DATE	PRE-IMPACT 1	IMPACT 2	INFLUENCE 3	PRE-IMPACT 5	POST-IMPACT 6
TDS mg/L	a) Spring runoff 19/4/83	-	684	318	471	-
	b) Storm event 19/6/83	-	1272	1024	477	720
	c) Dry weather 4/10/83	2172	1338	714	695	-
	d) Storm event 7/6/84	1631	2111	920	712	918
	e) Dry weather 1/10/84	2321	1491	1723	880	1108
	f) Spring runoff 9/4/85	519	444	361	218	302
NFR mg/L	a) Spring runoff 19/4/83	-	33	8	27	-
	b) Storm event 19/6/83	-	231	29	203	16
	c) Dry weather 4/10/83	38	45	49	65	-
	d) Storm event 7/6/84	15	88	14	23	10
	e) Dry weather 1/10/84	13	127	13	88	18
	f) Spring runoff 9/4/85	11	81	47	52	38
S. COND. µS/cm	a) Spring runoff 19/4/83	-	1187	581	866	-
	b) Storm event 19/6/83	-	2130	1717	808	1222
	c) Dry weather 4/10/83	3320	2210	1212	1163	-
	d) Storm event 7/6/84	2500	3480	1510	1142	1500
	e) Dry weather 1/10/84	3440	2310	2570	1370	1690
	f) Spring runoff 9/4/85	869	758	606	372	508
TKN mg/L as N	a) Spring runoff 19/4/83	-	14.8	0.72	5.65	-
	b) Storm event 19/6/83	-	33.5	4.70	2.50	3.45
	c) Dry weather 4/10/83	6.2	12	4.8	4.0	-
	d) Storm event 7/6/84	3.25	29	3.32	4.10	3.55
	e) Dry weather 1/10/84	8.0	30.0	-	-	-
	f) Spring runoff 9/4/85	2.30	22	3.00	2.50	2.60
DOC mg/L as C	a) Spring runoff 19/4/83	-	72	-	43	-
	b) Storm event 19/6/83	-	170	72	31	50
	c) Dry weather 4/10/83	55	127	51	49	-
	d) Storm event 7/6/84	40.2	96.0	53.2	30.8	49.2
	e) Dry weather 1/10/84	47.8	155.9	90.3	52.7	42.1
	f) Spring runoff 9/4/85	19.8	61.0	25.0	19.5	23.5
COD mg/L	a) Spring runoff 19/4/83	-	294	55.5	163	-
	b) Storm event 19/6/83	-	673	177	74.8	136
	c) Dry weather 4/10/83	156	347	159	147	-
	d) Storm event 7/6/84	136.5	471.7	111.8	154.5	143.6
	e) Dry weather 1/10/84	135.5	534.0	259.2	168.0	109.2
	f) Spring runoff 9/4/85	66.3	256.2	96.0	77.2	86.1
TP mg/L	a) Spring runoff 19/4/83	-	7.25	0.063	2.75	-
	b) Storm event 19/6/83	-	12.0	2.65	1.28	0.36
	c) Dry weather 4/10/83	0.68	5.9	0.98	0.72	-
	d) Storm event 7/6/84	0.44	13.7	0.66	2.55	0.825
	e) Dry weather 1/10/84	0.60	11.3	-	-	-
	f) Spring runoff 9/4/85	0.07	5.4	0.30	0.35	0.29

There was a small amount of NFR that could be attributed to the feedlot.

(ii) Major ions

The concentration of major ions in Shorncliffe Lake (Station 1) was highly variable, but consistently higher than that of the slough and the creeks. The downstream creek (Station 6) contained lesser amounts of HCO_3^- (T.ALK), K, Ca, and Mg, as compared to the slough composition.

(iii) Nutrients

Except for TKN, concentrations of nutrients in Shorncliffe Lake (Station 1) were low. In contrast, concentrations of the nutrients, including N, P and C, were very high at Station 2. The creek draining the slough (Station 3), as well as Ribstone Creek (Station 5), contained moderately high concentrations of all nutrients. Generally, the total phosphorus, TKN and ammonia comprised the major nutrient constituents in the creeks. Nutrient data indicated a marked contribution by the feedlot to the receiving, surface waters.

(iv) Metals

Except for Fe and Mn, the concentrations of metals were low at all stations. In the samples from Shorncliffe Lake (Station 1), Fe and Mn concentrations were approximately four to five times above detectable levels, whereas the samples from Station 2 and the creeks (Stations 3 and 6) contained Fe and Mn concentrations that were one and two orders of magnitude higher than those of Station 1. There was no apparent contribution of heavy metals by the feedlot to the receiving surface waters.

(b) Seasonal Loadings

(i) Physical parameters

The pH range for spring-runoff samples was 7.4-9.0, for storm-event surveys it was 7.8-9.1, and for the dry-weather surveys it was 8.1-9.4. Generally, spring-runoff samples had the lowest specific conductance. The storm-survey values were intermediate, while the dry-weather values were typically the highest encountered for any sampling survey. Only at Station 2 was the specific conductance highest for a storm-survey sample. The storm-survey samples contained higher concentrations of NFR (88-231 mg/L) than did all other surveys.

(ii) Major ions

Major ion concentrations were the lowest during the spring-runoff, with levels increasing by a factor of two for both storm and dry-weather surveys. For example, the Ca levels ranged from 5 to 30 mg/L during the spring runoff, and increased from 20 to 143 mg/L during the storm and dry-weather surveys.

ii) Nutrients

The highest nutrient levels, TP, TKN, and especially DOC, occurred during the storm-event surveys. The dry-weather levels were the next highest, but were variable, and the spring-runoff levels were the lowest. This trend was most apparent at Station 2.

(iv) Metals

The Fe levels were highest during the storm-event surveys, especially at Station 2. The remaining Fe levels were highly variable, and any obvious trends could not be identified. The same was generally true for Mn. Aluminum levels were highly variable without any apparent trend. The remaining metals were at, or near detection limits. This indicated that the feedlot was not contributing any significant quantities of heavy metals.

4.5.3 Statistical analyses

(a) Distance-Decay Model

The results of distance-decay model analyses are presented in Table 4.38 for the pooled data, and in Tables 4.39-4.41 for the seasonal data. A significant ($P \leq 0.05$) negative relationship between distance from the impact zone and HPC35, HPC20, ANA and FS counts was noted for the pooled data. For FUNGI, TC and FC, however, the relationship was not significant. The coefficient-of-determination (R^2) values for all variables were quite low. None exceeded 25.7%, and most were in the 5.9% range, indicating poor-fitting distance-decay equations. Because decay coefficients (B-values in Table 4.38) were quite small in magnitude, the hypothetical distance required to reduce the microbial count to 1 was substantial in most cases, ranging from 18 to 66 km.

A comparison of distance-decay coefficients (Tables 4.39-4.41) for the spring-runoff survey, showed that a significant negative relationship exists between distance from the impact zone and HPC35, HPC20, ANA, FUNGI, TC and FC. The R^2 values in most cases were satisfactory, ranging from 3 to 83%. This was caused primarily by the initial loadings, which were quite high for most of the microbial parameters. For the spring-runoff surveys, distance-decay equations were acceptable, as they were able to account for the

Table 4.38. Logarithmic distance-decay coefficients[a] for all data from Adams Ranch Ltd.

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σe	R^2	DISTANCE TO 1 COUNT (km)[b]
LOG HPC 35	310	4.56914 (37080)	-.000104[c]	.000018	33.67	.805459	.0985	43.55
LOG HPC20	316	5.011457 (102673)	-.000111[c]	.000021	25.73	.978637	.0757	45.14
LOG ANA	256	3.606143 (4037)	-.000199[c]	.000021	87.91	.851712	.2571	18.12
LOG FUNGI	260	1.914318 (82)	-.000029	.000018	2.60	.740573	.0099	66.01
LOG TC	160	2.868552 (738)	-.000067	.000035	3.63	1.127296	.0224	42.81
LOG FC	160	2.169520 (147)	-.000070	.000039	3.16	1.266713	.0196	30.99
LOG FS	160	2.941596 (874)	-.000101[c]	.000032	9.69	1.041929	.0577	29.12

[a] Model: LOG Y = LOG A + BD

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] Significant ($P \leq 0.05$)

Table 4.39. Logarithmic distance-decay coefficients[a] for spring-runoff data from Adams Ranch Ltd.

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σe	R^2	DISTANCE TO 1 COUNT (km)[b]
LOG HPC 35	118	5.020676 (104875)	$-.000183^c$	.000016	119.07	.4624	.5065	27.43
LOG HPC20	119	6.040133 (1096814)	$-.000165^c$	.000012	163.23	.3563	.5824	36.60
LOG ANA	60	4.125804 (13359)	$-.000454^c$	.000026	289.16	.5212	.8329	.90
LOG FUNGI	60	2.902261 (798)	$-.000107^c$	.000011	92.74	.2169	.6152	27.12
LOG TC	60	2.776894 (598)	$-.000149^c$	.000056	6.92	1.1087	.1065	1.86
LOG FC	60	1.955501 (90)	$-.000214^c$	.000045	22.38	.8856	.2783	9.1
LOG FS	60	2.762952 (579)	-.000086	.000059	2.13	1.1544	.0354	32.12

[a] Model: LOG Y = LOG A + BD

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] Significant ($P \leq 0.05$)

Table 4.40. Logarithmic distance-decay coefficients[a] for storm-event data from Adams Ranch Ltd.

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σe	R^2	DISTANCE TO 1 COUNT (km)[b]
LOG HPC 35	78	4.433156 (27111)	-.000103[c]	.000039	6.94	.8684	.0836	43.04
LOG HPC20	79	4.626693 (42334)	-.000144[c]	.000036	15.91	.8003	.1712	32.12
LOG ANA	76	3.117742 (1311)	-.000080[c]	.000036	4.69	.7993	.0596	38.97
LOG FUNGI	80	1.956583 (90)	-.000035	.000027	1.60	.6289	.0200	55.90
LOG TC	40	3.283277 (1919)	-.000058	.000052	1.22	.8427	.0310	56.60
LOG FC	40	2.655016 (451)	-.000034	.000066	.27	1.0642	.0069	78.08
LOG FS	40	3.031862 (1076)	-.000075	.000052	2.06	.8397	.0513	40.42

[a] Model: LOG Y = LOG A + BD

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] Significant ($P \leq 0.05$)

Table 4.41. Logarithmic distance-decay coefficients[a] for dry-weather data from Adams Ranch Ltd.

VARIABLE	N	LOG A (ANILOG A)	B	S.E.(B)	F-VALUE	σe	R^2	DISTANCE TO 1 COUNT (km)[b]
LOG HPC 35	114	4.192764 (15587)	-.000025	.000034	.55	.9288	.0048	167.71
LOG HPC20	118	4.230859 (17016)	-.000035	.000029	1.37	.8212	.0116	120.88
LOG ANA	120	3.644946 (4415)	-.000143[c]	.000029	23.24	.8233	.1645	25.48
LOG FUNGI	120	1.392170 (24)	.000013	.000022	.34	.6284	.0028	—
LOG TC	60	2.683726 (482)	.000008	.000061	.02	1.2070	.0003	—
LOG FC	60	2.059875 (114)	.000049	.000072	.46	1.4073	.0079	—
LOG FS	60	3.060062 (1148)	-.000134[c]	.000054	6.21	1.054787	.0967	22.83

[a] Model: LOG Y = LOG A + BD

[b] Hypothetical distance required to reduce microbial count to 1 unit (calculated by extrapolation of the distance decay equation).

[c] Significant ($P \leq 0.05$)

large amount of variation in the microbial counts. For the storm-event and dry-weather surveys, however, distance-decay equations were found to be unsatisfactory. Significant negative relationships between distance and HPC35, HPC20 and ANA were observed for the storm-event surveys. This was also true for ANA and FS in the dry-weather surveys, as the R^2 values were generally low; none exceeded 18%.

In summary, distance-decay equations were generally not satisfactory, as they failed to account for most of the variation in microbial counts. They can be useful, however, when initial loadings at the single-source impact zone are very high.

(b) Multiple-Regression Model

Multiple-regression equations, based on the stepwise technique for the pooled data, are presented in Table 4.42. All independent variables in these equations were found to be significant at $P \leq 0.01$. For the pooled data, several of these variables were found to have an influence on microbial counts. Collectively, they accounted for most of the variation, as shown by very large R^2 values that ranged from 87.9-98.9%. Independent variables such as DIST, TEMP, TURB, pH, NO_2+NO_3 and NH_3 occurred most frequently in the regression equations. There were some correlation coefficients higher than 0.90 that could give rise to the multicollinearity problem. Specifically, correlations between FR.SCOND, TDS.SCOND, FR.TDS, TKN.TP, R2D.R3D, R2D.R7D and R3D.R7D were significantly ($P \leq 0.01$) positive and higher than 0.90. These variables did not occur together very frequently in the regression equations, however. Therefore, multicollinearity was not a problem in this data set.

Table 4.42. Multiple-regression equations based on pooled data from Adams Ranch Ltd.

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	5.4732	Intercept	8.1234	Intercept	4.2487	Intercept	5.8604	Intercept	0.3967	Intercept	12.2438	Intercept	2.5965
TEMP	0.0747	PH	-0.3900	TURB	-6.8011	DIST	-0.00005	DIST	-0.00004	DIST	0.0001	DIST	-0.0000
TURB	1.4413	SCOND	-0.0034	PARTN	-0.9843	DO2	-0.0658	TURB	2.3760	PH	-1.3968	TEMP	-0.1773
PH	-0.3078	FR	0.0046	PARTC	0.3465	TURB	0.8876	NO2	23.9319	SCOND	0.0058	DO2	0.1623
DOC	-0.0117	PARTC	0.1629	DOC	-0.0457	PH	-0.3602	NO2NO3	-1.3980	TDS	-0.0075	TURB	0.5208
NH3	0.2265	DOC	-0.0556	NO2	77.2039	FR	0.0004	R2D	-0.1176	PARTN	6.2622	NFR	0.0319
BOD	-0.0321	NH3	-0.1812	NO2NO3	0.9484	NFR	0.0130	R7D	0.0962	COD	-0.0386	NH3	0.1416
NO2	46.2275	BOD	0.1298			DOC	-0.0342			OP	-0.4787	COD	-0.0090
OP	-0.1213	NO2NO3	5.6395							R7D	0.0574	NO2	46.1514
NO2NO3	0.8887											OP	-0.2430
												R7D	0.0400
N	155	N	155	N	92	N	120	N	78	N	78	N	78
R2	0.8797	R2	0.9773	R2	0.9778	R2	0.9481	R2	0.9748	R2	0.9828	R2	0.9892
M.S.E.	0.0585	M.S.E.	0.0161	M.S.E.	0.0164	M.S.E.	0.0182	M.S.E.	0.0250	M.S.E.	0.0225	M.S.E.	0.0107

Regression equations based on the seasonal data are presented in Tables 4.43-4.45. For the spring-runoff survey, DIST, TEMP, TURB, DO_2, pH, SCOND and FR accounted for most of the variation, from 89-99%. For the storm-event survey, DIST, TEMP, DO_2 and TURB accounted for most of the variation, from 89-97%. Similarly, for the dry-weather survey, DIST, TEMP, DO_2, TURB, pH and SCOND accounted for most of the variation in microbial counts, ranging from 93-99%.

In summary, for the Adams Ranch Ltd. data, most of the variation in microbial counts could be explained by the independent variables monitored in this study. Specifically, DIST, TEMP, pH, SCOND, TURB, DO_2 and NO_2+NO_3 were found to appear most frequently in the regression equations, implying their importance as predictor variables for microbial concentrations. Therefore, in any future monitoring programs and feedlot impact studies, these variables should be emphasized.

Table 4.43. Multiple-regression equations based on spring-runoff data from Adams Ranch Ltd.

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	-31.5528	Intercept	-61.7806	Intercept	-68.8240	Intercept	1.6345	Intercept	116.4131	Intercept	-0.0757	Intercept	112.4969
DIST	-0.0000	DIST	-0.0000	DIST	-0.0005	DIST	-0.0000	DIST	-0.0000	DIST	-0.0002	DIST	-0.0002
TEMP	1.2806	TEMP	2.2577	TEMP	5.5939	TEMP	0.0509	TEMP	-3.6883	TEMP	0.1464	TEMP	-3.5942
DO2	-0.7950	DO2	-1.3715			TURB	1.1525	DO2	2.1294	DO2	-0.0529	DO2	2.1384
TURB	3.6873	TURB	4.2460					TURB	-1.9250	TURB	3.6361	TURB	-2.6270
PH	3.3711	PH	6.4902					PH	-11.2781	SCOND	-0.0127	PH	-10.6206
SCOND	-0.0060	SCOND	-0.0066					FR	0.0117	FR	0.0150	SCOND	-0.0034
FR	0.0044	FR	0.0021									FR	0.0127
N	96	N	96	N	36	N	60	N	48	N	48	N	48
R2	0.8914	R2	0.9647	R2	0.9854	R2	0.9381	R2	0.9893	R2	0.9827	R2	0.9959
M.S.E.	0.0659	M.S.E.	0.0137	M.S.E.	0.0247	M.S.E.	0.0095	M.S.E.	0.0148	M.S.E.	0.0213	M.S.E.	0.0056

Table 4.44. Multiple-regression equations based on storm-event data from Adams Ranch Ltd.

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	6.7409	Intercept	3.9917	Intercept	6.3829	Intercept	5.4187	Intercept	8.4627	Intercept	9.2807	Intercept	9.4419
DIST	0.0001	DO2	-0.1646	DIST	0.0001	DIST	-0.0001	DIST	0.0002	DIST	0.0004	DIST	0.0002
TEMP	-0.2258	TURB	7.5723	TEMP	-0.3030	TEMP	-0.2802	TEMP	-0.4842	TEMP	-0.6159	TEMP	-0.5490
DO2	-0.2675			DO2	-0.0795	DO2	0.0787	DO2	-0.2071	DO2	-0.4106	DO2	-0.2538
TURB	8.9189			TURB	6.2779	TURB	2.1329	TURB	10.6806	TURB	16.1709	TURB	10.4396
N	59	N	59	N	56	N	60	N	30	N	30	N	30
R2	0.8926	R2	0.9578	R2	0.9122	R2	0.9367	R2	0.9589	R2	0.9701	R2	0.9610
M.S.E.	0.0330	M.S.E.	0.0189	M.S.E.	0.0113	M.S.E.	0.0259	M.S.E.	0.0129	M.S.E.	0.0185	M.S.E.	0.0165

Table 4.45. Multiple-regression equations based on dry-weather data from Adams Ranch Ltd.

LOG HPC35		LOG HPC20		LOG ANA		LOG FUNGI		LOG TC		LOG FC		LOG FS	
Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value	Xi	B-value
Intercept	-1.3575	Intercept	8.6701	Intercept	3.3882	Intercept	-0.9673	Intercept	3.7984	Intercept	-2.8394	Intercept	1.2021
DIST	0.0001	DIST	0.0003	TEMP	0.1021	DIST	0.0003	DIST	0.0004	DIST	0.0004	DIST	0.0001
TEMP	0.1432	TEMP	-0.2988	TURB	6.8588	TEMP	-0.1358	TEMP	0.2082	TEMP	0.2419	TEMP	0.0994
DO2	0.1740	DO2	-0.1080	PH	-0.6491	DO2	-0.0351	TURB	7.3944	DO2	-0.2367	DO2	-0.1610
TURB	6.4637	TURB	6.4644	SCOND	0.0057	TURB	3.2016	PH	-0.5136	TURB	10.2024	TURB	8.4447
PH	-0.2160	PH	-0.8026	FR	-0.0053	PH	-0.0780	SCOND	0.0113	PH	-0.6078	PH	-0.6035
FR	-0.0037	SCOND	0.0047			SCOND	0.0033	TDS	-0.0128	SCOND	0.0193	SCOND	0.0151
TDS	0.0070	FR	-0.0037			FR	-0.0020			FR	-0.0069	FR	-0.0060
										TDS	-0.0165	TDS	-0.0126
N	104	N	106	N	108	N	108	N	54	N	54	N	54
R2	0.9819	R2	0.9706	R2	0.9318	R2	0.9787	R2	0.9772	R2	0.9864	R2	0.9892
M.S.E.	0.0150	M.S.E.	0.0219	M.S.E.	0.0583	M.S.E.	0.0095	M.S.E.	0.0411	M.S.E.	0.0325	M.S.E.	8.0671

5.0 GENERAL DISCUSSION

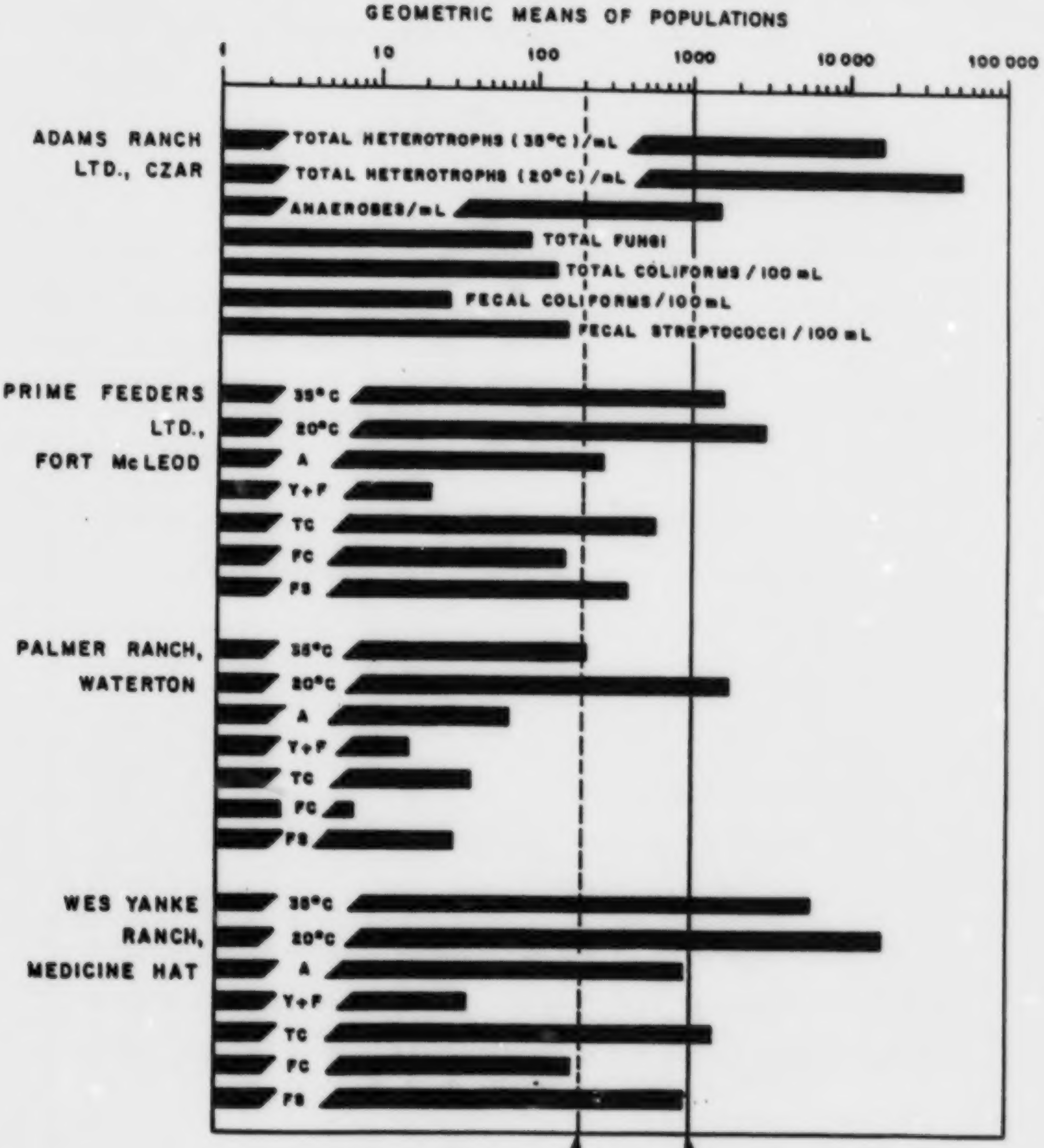
Surveys were conducted at each feedlot during spring-runoff, storm-event and dry-weather conditions to determine the level and extent of seasonal influences on the quality of adjacent surface waters. As the result of local weather conditions, however, the predominant type of survey conducted at each feedlot was variable. For example, more spring-runoff surveys were conducted at Palmer Ranch than at other feedlots (Table 4.1), while at Wes Yanke Ranch more dry-weather surveys than spring-runoff or storm-event surveys were carried out. Moreover, due to the complexity and uniqueness of each feedlot that was examined, it was difficult to extrapolate information regarding impact potential from one feedlot and apply it to another. The results also indicated that the pollution-potential and containment-loading profile of feedlots in Alberta appeared to be situation-bound and site-specific. Some specific and major findings of this study, based on extensive microbiological, chemical and statistical data, are presented here.

5.1 Microbiological Analyses

Notwithstanding the sampling-station and seasonal influences, an overall picture of microbiological loadings was developed by using the geometric mean (GM) of all values acquired for each parameter during all surveys at each feedlot. Using these GMs, a histogram was prepared depicting the microbiological profile of each feedlot (Figure 5.1).

FIGURE 5.1

MICROBIOLOGICAL PROFILE OF FOUR FEEDLOT STUDY SITES IN ALBERTA



MAXIMUM LIMITS FOR FECAL AND TOTAL COLIFORM LEVELS IN PRIMARY CONTACT RECREATIONAL WATERS (ALBERTA ENVIRONMENT).

Densities of TC, FC and FS were highly variable among the four feedlots. Specifically, the highest levels were at Wes Yanke Ranch, where GMs of 1400 TC, 170 FC and 835 FS/100 mL were observed (Appendix 9.5.3). The TC and FC values exceeded or closely approached the guidelines for Canadian/Alberta recreational water quality (2, 6) and may represent a potential health hazard. The next highest levels were observed at Prime Feeders Ltd., with 600 TC, 140 FC and 370 FS/100 mL. This was followed by Adams Ranch Ltd., where densities of TC, FC and FS were 430, 71 and 460/100 mL, respectively. Finally, the lowest concentrations of 35 TC, 7 FC and 34 FS/100 mL were observed at Palmer Ranch.

Levels of aerobic heterotrophic bacteria are frequently increased in water bodies with high nutrient content and organic enrichment. Anaerobic heterotrophs are also present in high numbers in animal fecal wastes. Thus, high numbers of these organisms in receiving waters may reflect recent fecal contamination. The survey results indicated that the highest levels of aerobic heterotrophic bacteria were observed at Adams Ranch Ltd., where GMs of aerobic (20°C, 35°C) and anaerobic heterotrophs were 51,000, 17,000 and 1,400/mL, respectively. Intermediate levels were demonstrated in samples from Wes Yanke Ranch, where GMs of aerobic (20°C, 35°C) and anaerobic heterotrophic bacteria equalled 17,000, 5,200 and 990/mL, respectively. Samples from Prime Feeders Ltd., recorded even lower densities of these organisms with GMs of 2,700, 1,300 and 240/mL, respectively. Finally, samples from Palmer Ranch yielded the lowest counts of these organisms, with GMs of 1,700, 210 and 70/mL, respectively, indicating little feedlot impact. These results indicated that surface waters ajacent to Adams Ranch Ltd. and

Wes Yanke Ranch were highly eutrophic, while those of the other two feedlots were relatively unpolluted.

High numbers of fungi are generally indicative of an established eutrophic situation. Levels of yeast and molds were quite low at all feedlot sites. The highest level (GM of 82 CFU/mL) was demonstrated at Adams Ranch Ltd., while fungal densities were very low at other feedlots, and ranged from 14-36 CFU/mL.

Also, the GMs of all data of each microbiological parameter per survey type (spring-runoff, storm-event, and dry-weather surveys) for each feedlot are graphically presented in Figures 5.2a, 5.2b, 5.3a, 5.3b, 5.4a, 5.4b, 5.5a and 5.5b). The significance of these profiles is explained below.

(a) Palmer Ranch, Waterton

Densities of aerobic heterotrophic bacteria, pollution-indicator bacteria and fungi were lowest at Palmer Ranch, where little or no eutrophic conditions appeared to be present. This was probably caused by the low temperature and the fast-flowing nature of the Waterton River, which would tend to minimize the effect of potential pollutants.

The impact of feedlot runoff on water quality in the adjacent receiving water was clearly demonstrated more frequently at Palmer Ranch than at the other feedlots. Although densities of microbial parameters were usually low, they were significantly higher at Station 3 than at Station 1 or Station 4 (Figures 5.2a, 5.2b), but returned to high levels at Station 5 and 6 for no apparent reason. The impact was most strongly demonstrated during the storm-event survey, when levels of FC at Station 3 exceeded by about 2.5 X the recommended level (200/100 mL) for the guidelines for Canadian/

FIGURE 5.2 a
SEASONAL LOADINGS (GEOMETRIC MEANS) OF MICROBIAL LEVELS
PALMER RANCH

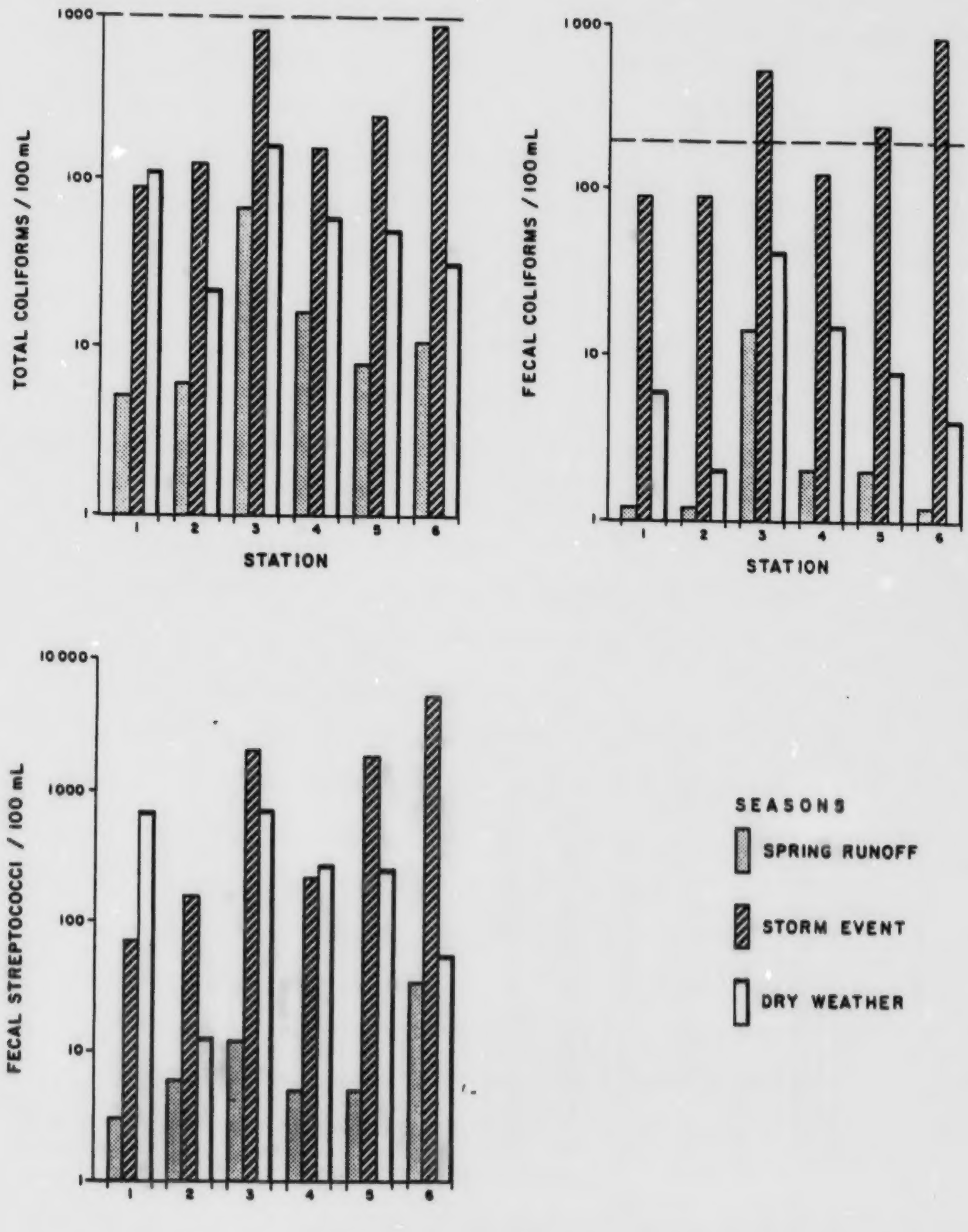
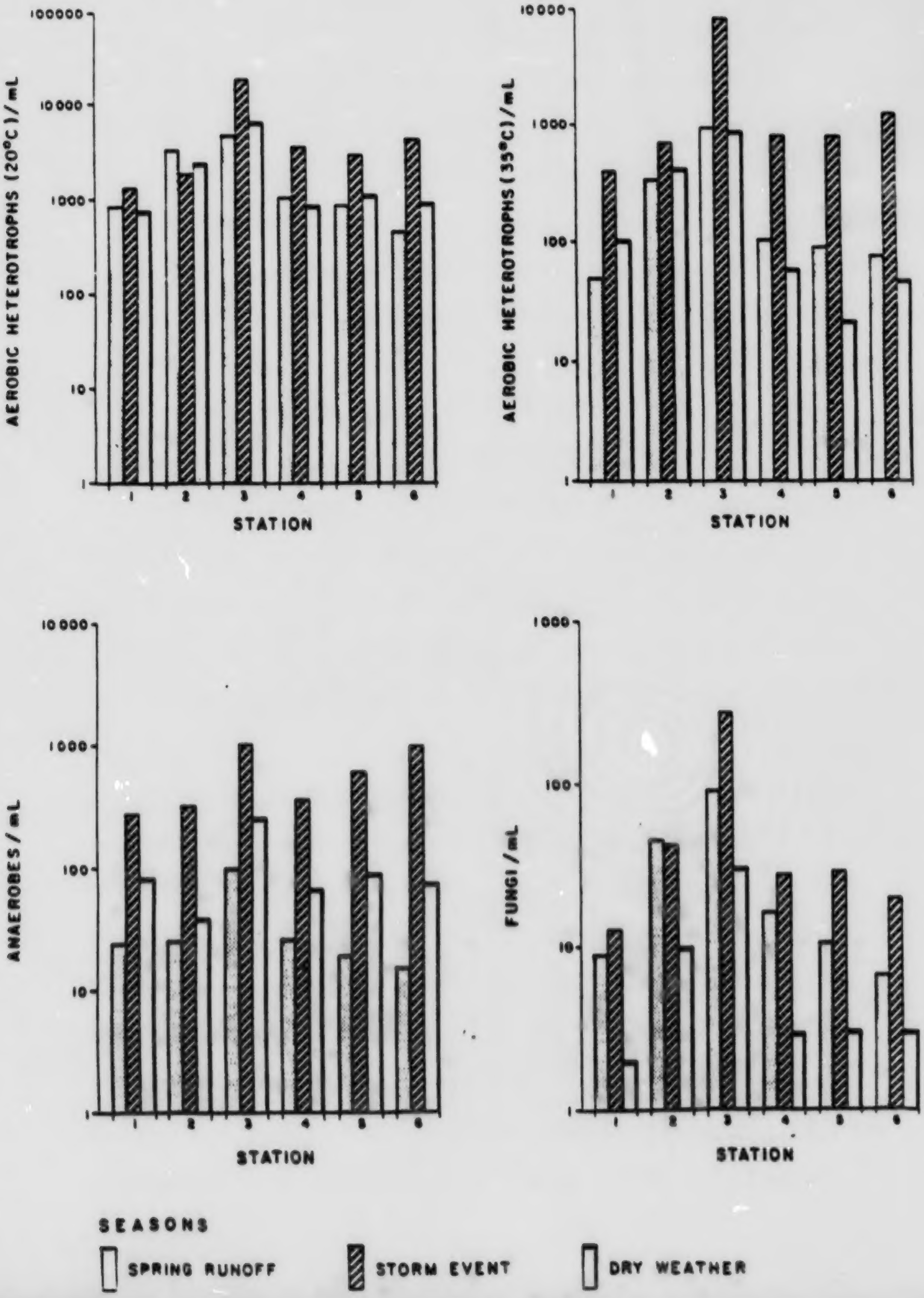


FIGURE 5.2 b

SEASONAL LOADINGS (GEOMETRIC MEANS) OF MICROBIAL LEVELS
PALMER RANCH



Alberta recreational water quality (2, 6), as indicated by the dotted line in Figure 5.2a.

(b) Prime Feeders Ltd., Fort McLeod

The overall geometric means of all microbial parameters obtained at the feedlot site were generally low (Figure 5.1). When GMs of survey types were considered, however, the ratio of FC values to TC and FS values were high (Figure 5.3a) in comparison to corresponding values obtained at other feedlots. In addition, during the storm-event surveys the geometric mean of FC values at this feedlot surpassed the guidelines for Canadian/Alberta recreational quality (2, 6) (as indicated by the dotted line in Figure 5.3a). This indicates that high levels of TC, FC and FS were discharged to the receiving waters in the feedlot runoff. The feedlot impact was not clearly demonstrated during most surveys because upstream levels of the pollution-indicator and heterotrophic bacteria and fungi were similar to, or as high as, downstream levels (Figures 5.3a, 5.3b).

(c) Wes Yanke Ranch, Medicine Hat

The highest overall TC, FC and FS geometric means were obtained from the surveys conducted at this feedlot (Figure 5.1). For example, the guidelines for Canadian/Alberta recreational water quality (2, 6) for TC and FC were usually exceeded at all sampling stations during dry-weather and storm-event surveys (Figure 5.4a). In general, there appeared to be a constantly high input of TC, FC, FS and aerobic, heterotrophic bacteria and fungi into receiving waters at this feedlot. However, the contribution was not caused entirely by the feedlot runoff because levels of these parameters were usually equal to, or significantly higher than, those at stations upstream and downstream of the feedlot (Station 1 and 6,

FIGURE 5.3 a

SEASONAL LOADINGS (GEOMETRIC MEANS) OF MICROBIAL LEVELS
PRIME FEEDERS LTD.

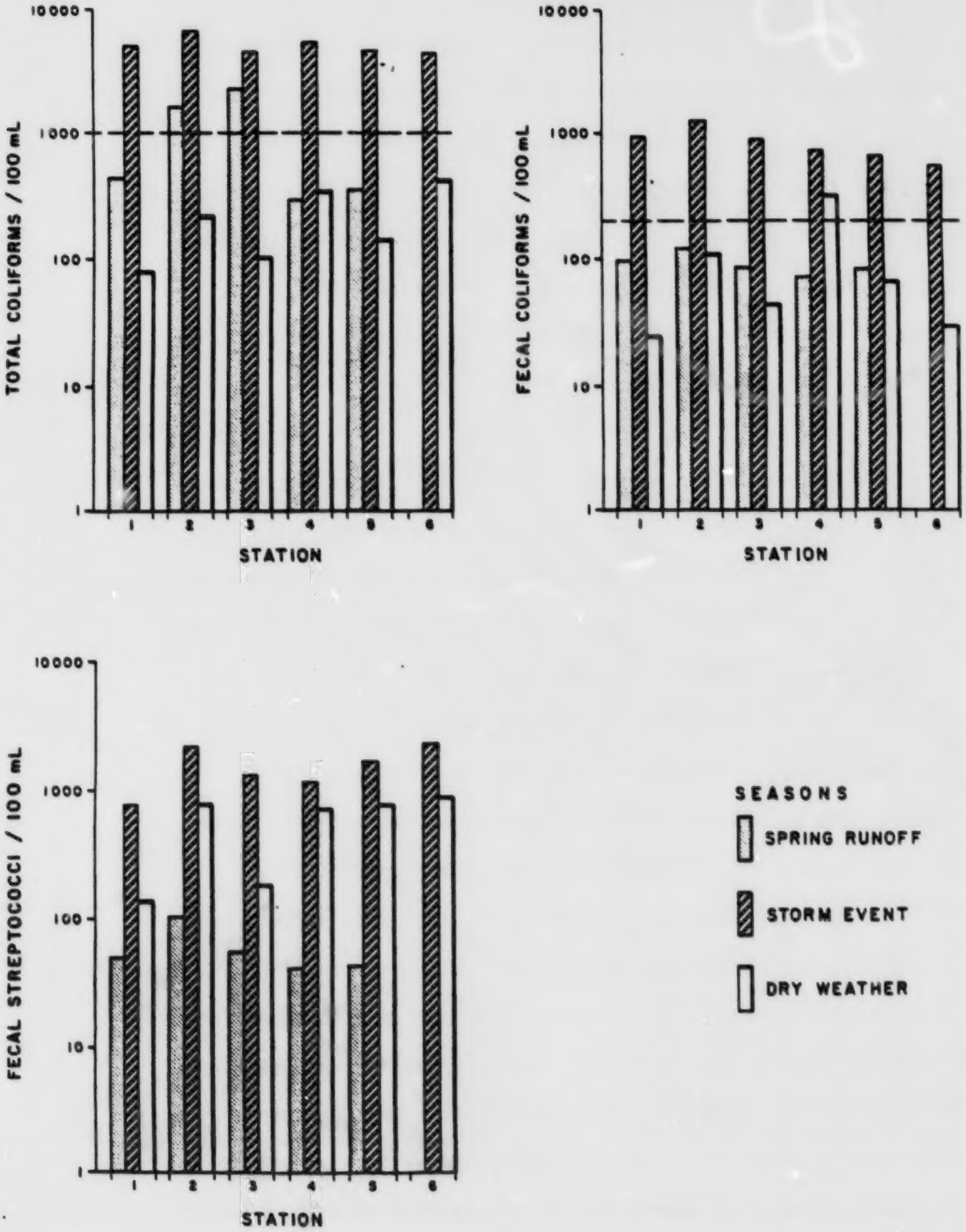


FIGURE 5.3b

SEASONAL LOADINGS (GEOMETRIC MEANS) OF MICROBIAL LEVELS PRIME FEEDERS LTD.

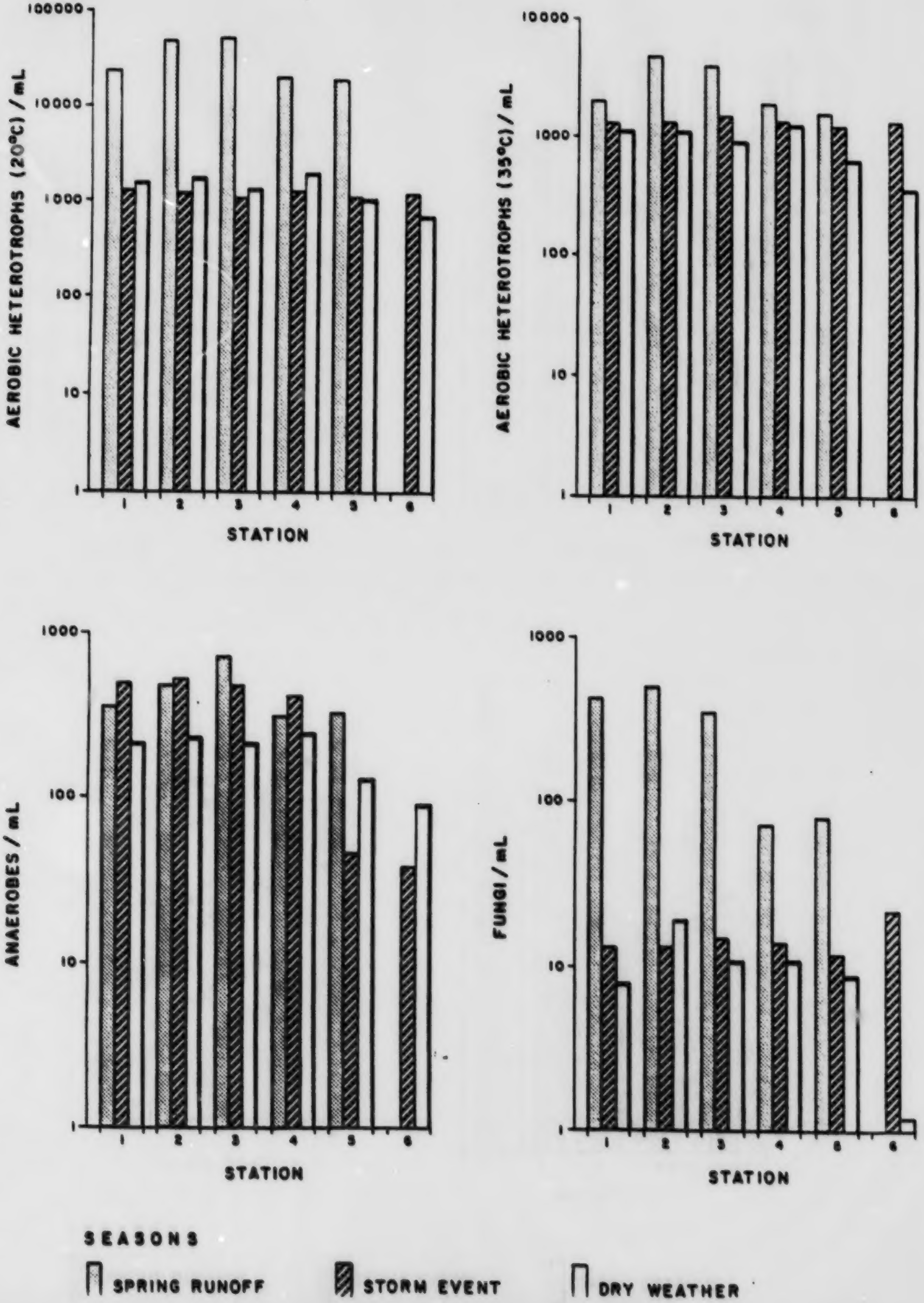


FIGURE 5.4 a

SEASONAL LOADINGS (GEOMETRIC MEANS) OF MICROBIAL LEVELS
WES YANKE RANCH

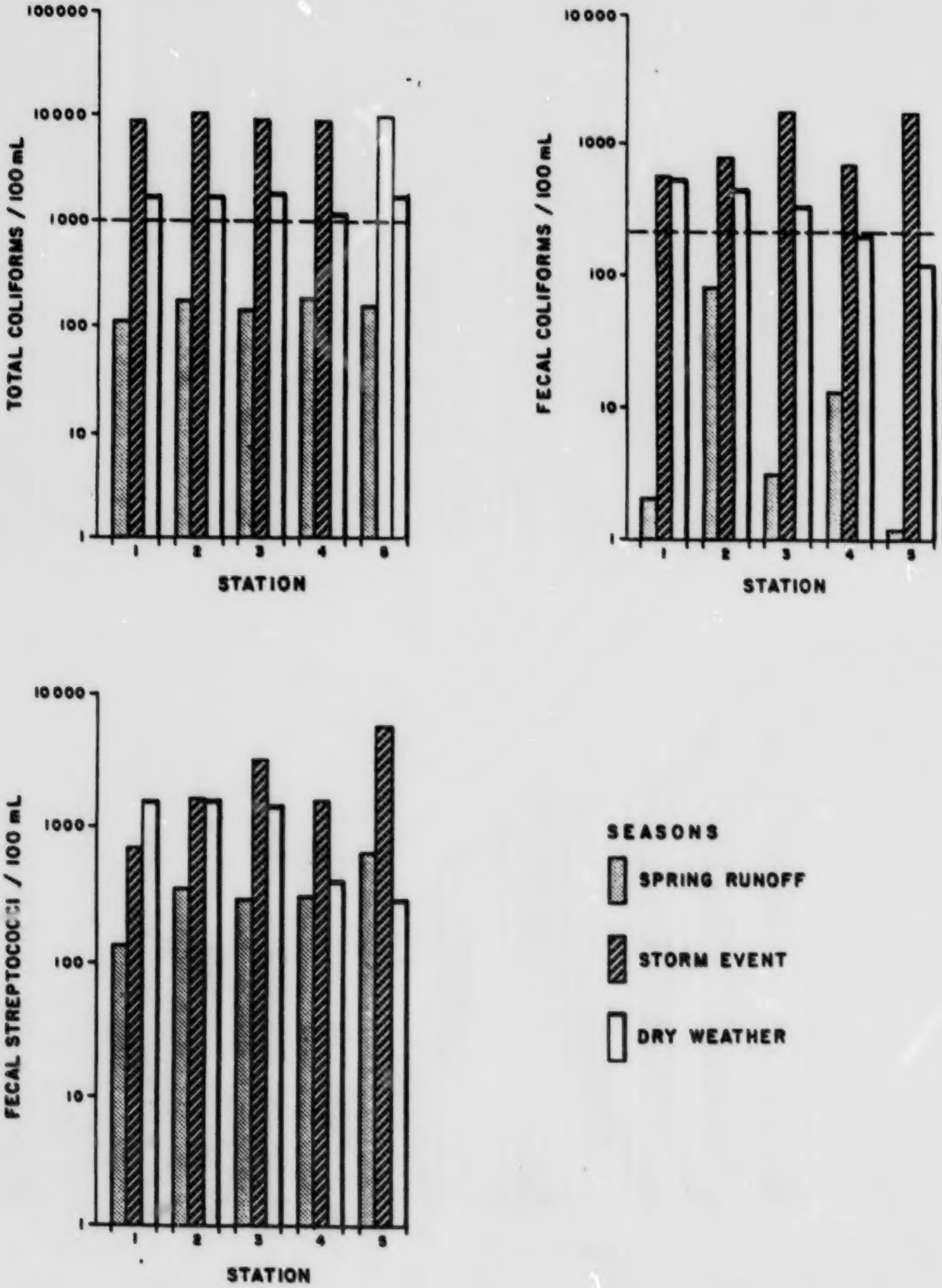
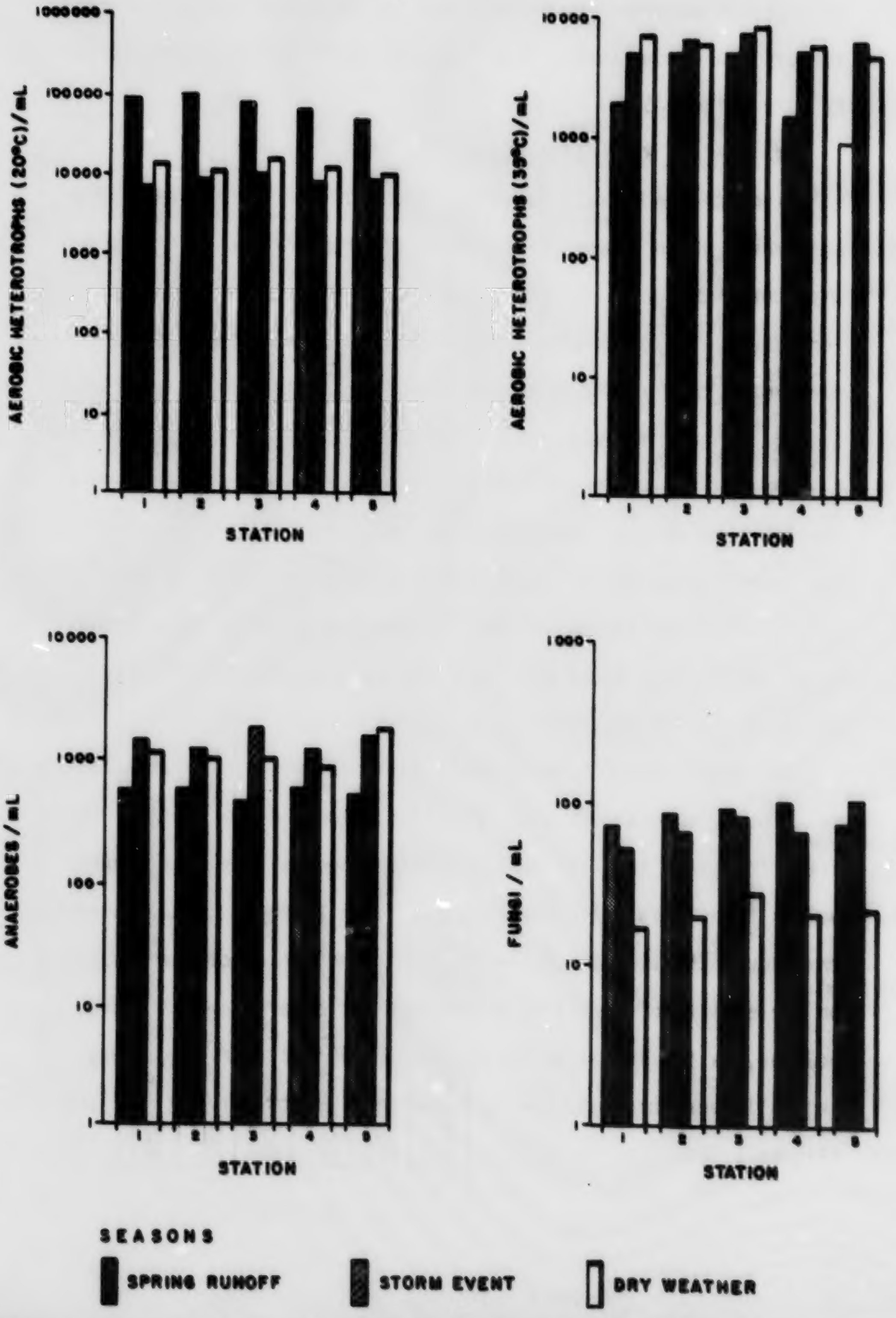


FIGURE 5.4 b

SEASONAL LOADINGS (GEOMETRIC MEANS) OF MICROBIAL LEVELS WES YANKE RANCH



respectively). This indicated the presence of contributions from other non-point sources (Figures 5.4a, 5.4b). Exceptions to this observation occurred during both the spring-runoff and storm-event surveys, when some impact from feedlot runoff was demonstrated for FC only (Figure 5.4a).

(d) Adams Ranch Ltd., Czar

Although the overall geometric means of the TC, FC and FS did not seem high in comparison to those of other feedlots (Figure 5.1), a closer examination of individual survey data showed a large contribution of these organisms at Station 2, which was located in the impact zone at the slough adjacent to the feedlot (Figure 5.5a). Since the slough normally drained at a relatively slow rate, however, these high bacterial levels did not tend to impact water quality adversely at downstream stations, resulting in an overall low geometric means for these bacteria. The levels of TC and FC, though, exceeded the guidelines for Canadian/Alberta recreational water quality (2, 6) at Station 2 during all seasons, and often exceeded them at Stations 5 and 6 (Figure 5.5a).

The densities of heterotrophic bacteria were higher at Adams Ranch Ltd., than at all other feedlots (Figure 5.1). This situation, plus the high fungal levels found at this site, typically occurs in nutrient-rich environments, such as those that existed in the slough (Station 2) of the feedlot. Any impact of feedlot runoff on the quality of receiving waters was not clearly demonstrated, however, as the levels of heterotrophic bacteria and fungi were generally very high and nearly comparable at most of the stations (Figure 5.5b).

FIGURE 5 5a

SEASONAL LOADINGS (GEOMETRIC MEANS) OF MICROBIAL LEVELS
ADAMS RANCH LTD.

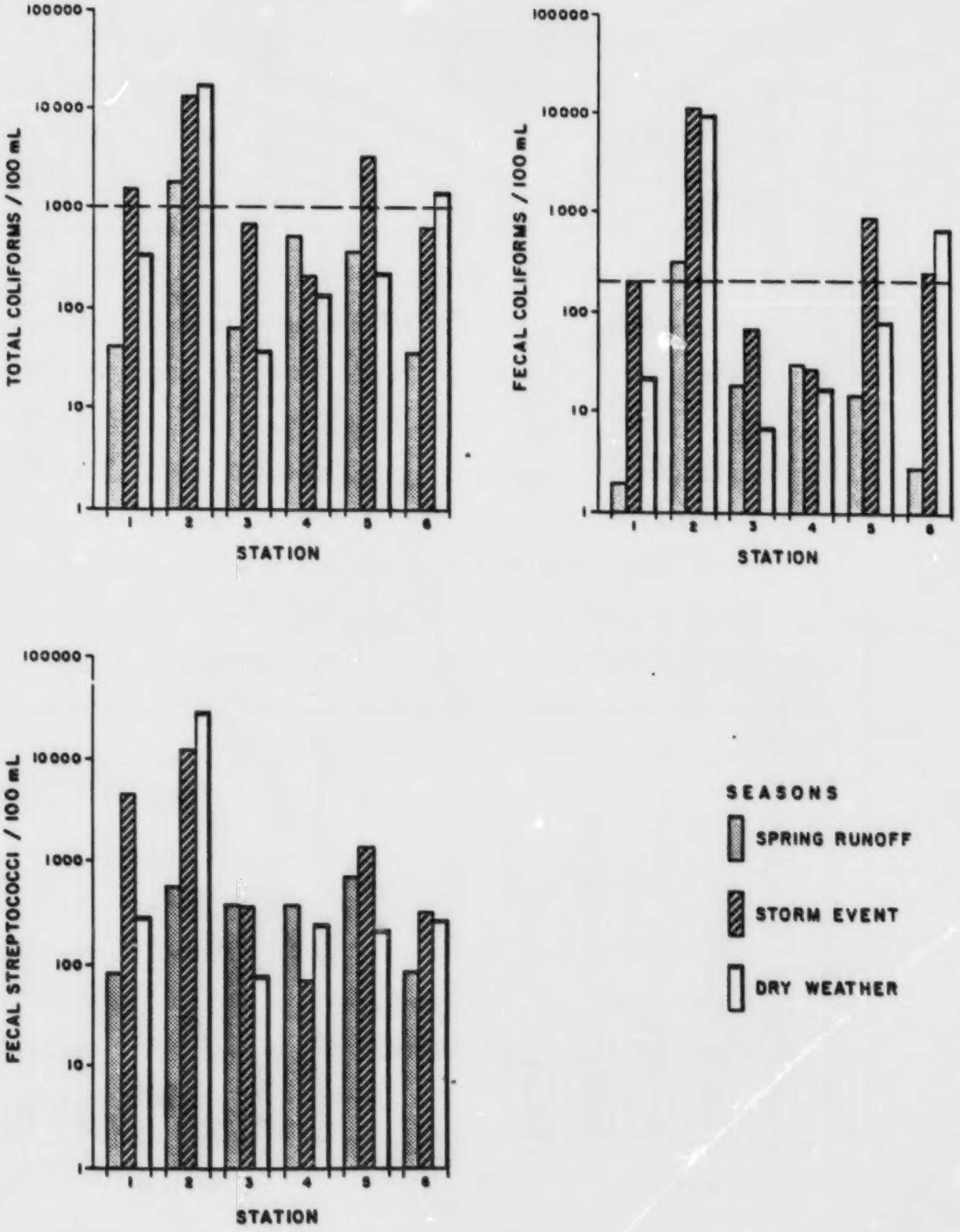
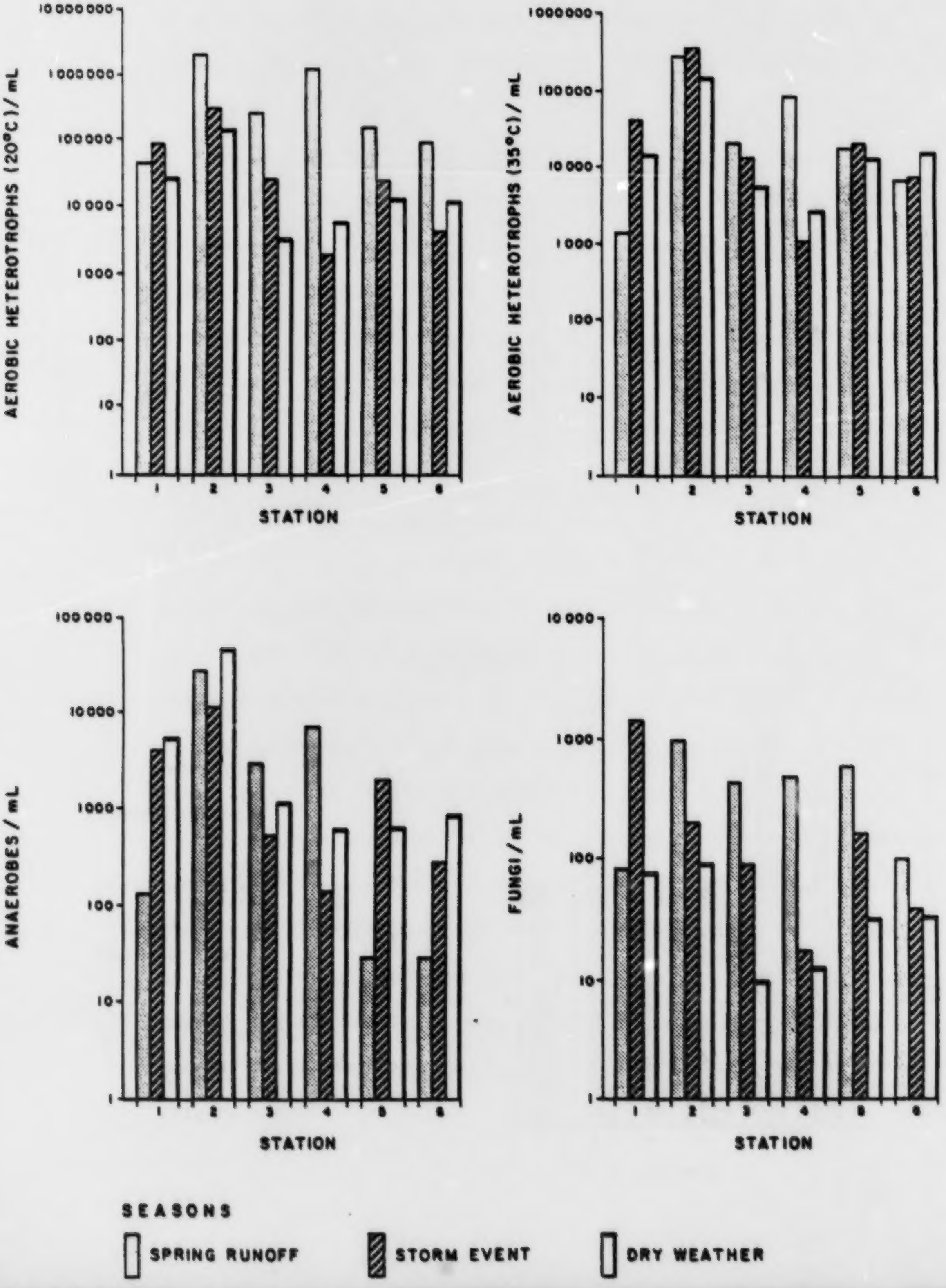


FIGURE 5.5 b

SEASONAL LOADINGS (GEOMETRIC MEANS) OF MICROBIAL LEVELS

ADAMS RANCH LTD.



5.2 Physical and Chemical Analyses

The impact of chemical constituents from feedlot wastes on the receiving waters was evaluated from data obtained at the four feedlots during various surveys conducted from 1983 through 1985. The magnitude of the impact on the watercourses varied from feedlot to feedlot, and with the conditions at the time of sampling. In general, the impact of feedlot runoff was observed on specific chemical parameters at the Palmer Ranch and Adams Ranch Ltd., and very little, if any, impact was noted at the Prime Feeders Ltd., and Wes Yanke feedlots. Selected data of various parameters are included in graphical format to illustrate both seasonal and station trends and variations, and impact and non-impact situations. No hydrological data were compiled for this study. Work done by Lakshman (15) in a Saskatchewan feedlot study (1976-79), however, suggests that the large majority of surface water runoff from a feedlot in the Canadian prairies would occur as the result of snowmelt during the spring. This fact should be kept in mind when attempting to assess the overall impact of surface drainage from the feedlot, based on the concentration values of the receiving streams alone.

(a) Palmer Ranch, Waterton

i) Physical Parameters

A small impact for specific conductance and TDS was noted (Figure 5.6). No impact on suspended solids or other physical parameters was observed, which indicated that feedlot input to the Waterton River was negligible.

ii) Major Ions

A slight impact for Ca, Mg, and total alkalinity was apparent (Figures 5.7 and 5.8). These major ion concentrations in the feedlot stream were approximately 20% higher than levels in the Waterton River. The remaining major ions were essentially constant.

iii) Nutrients

A moderate impact for TP and TKN was noted, together with a sporadic NO_2+NO_3 impact (Figures 5.9, 5.10, and 5.11). These parameters increased within the stream that traversed the feedlot. The stream did not appear to affect the Waterton River, however. No affect was evident on the remaining nutrients, such as DOC and COD, which remained low in all samples for all events. The ammonia data contained some erratic high values (Figure 5.12), which may be a result of non-representative sampling difficulties.

iv) Metals

No affect was noted for any of the metal parameters. Metal ion values were consistently at, or near, detectable levels.

b) Prime Feeders Ltd, Fort McLeod

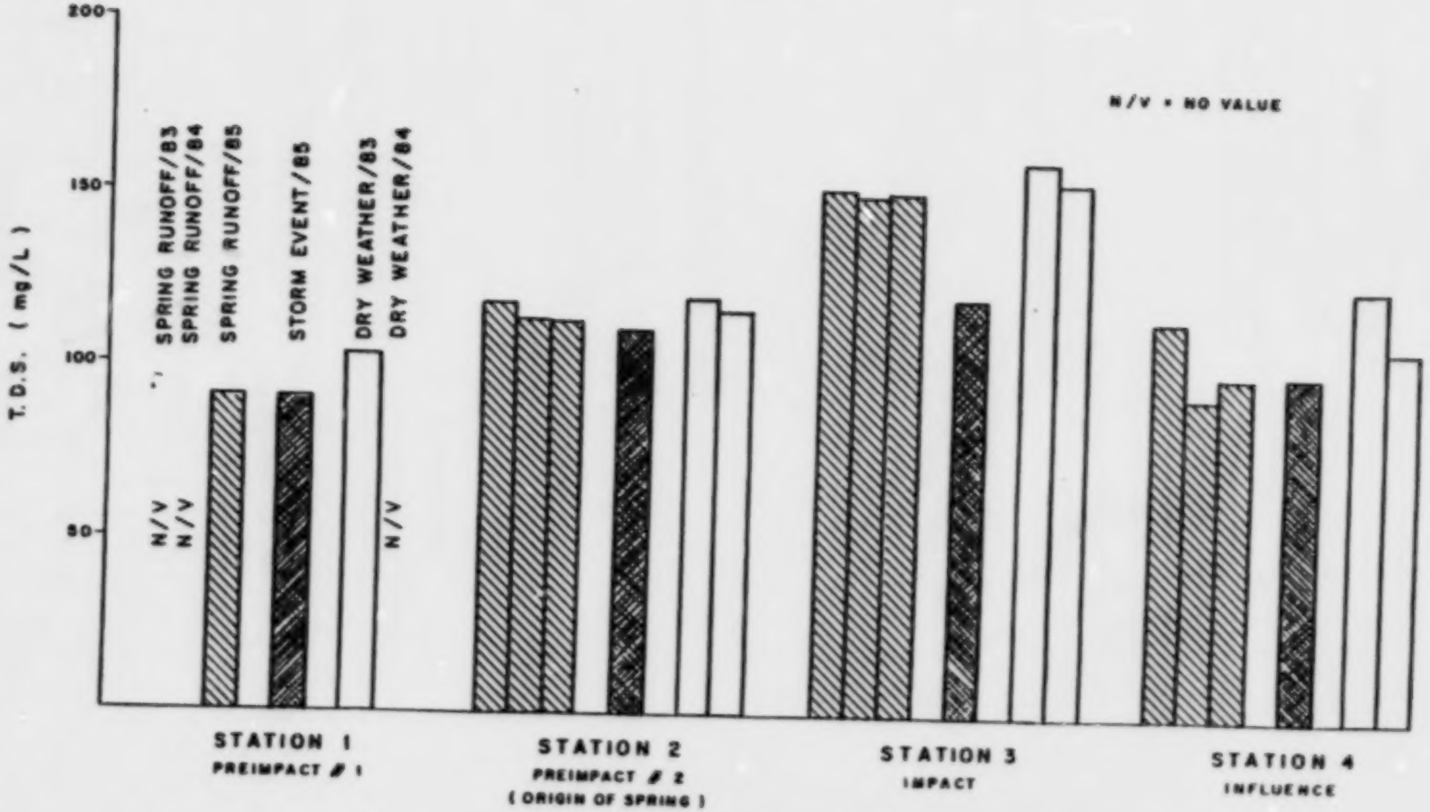
i) Physical Parameters

No apparent affect was observed. Information on TDS is presented in (Figure 5.18).

ii) Major Ions

The concentrations were essentially constant from site to site. No evidence was seen of feedlot contributions to the major ions.

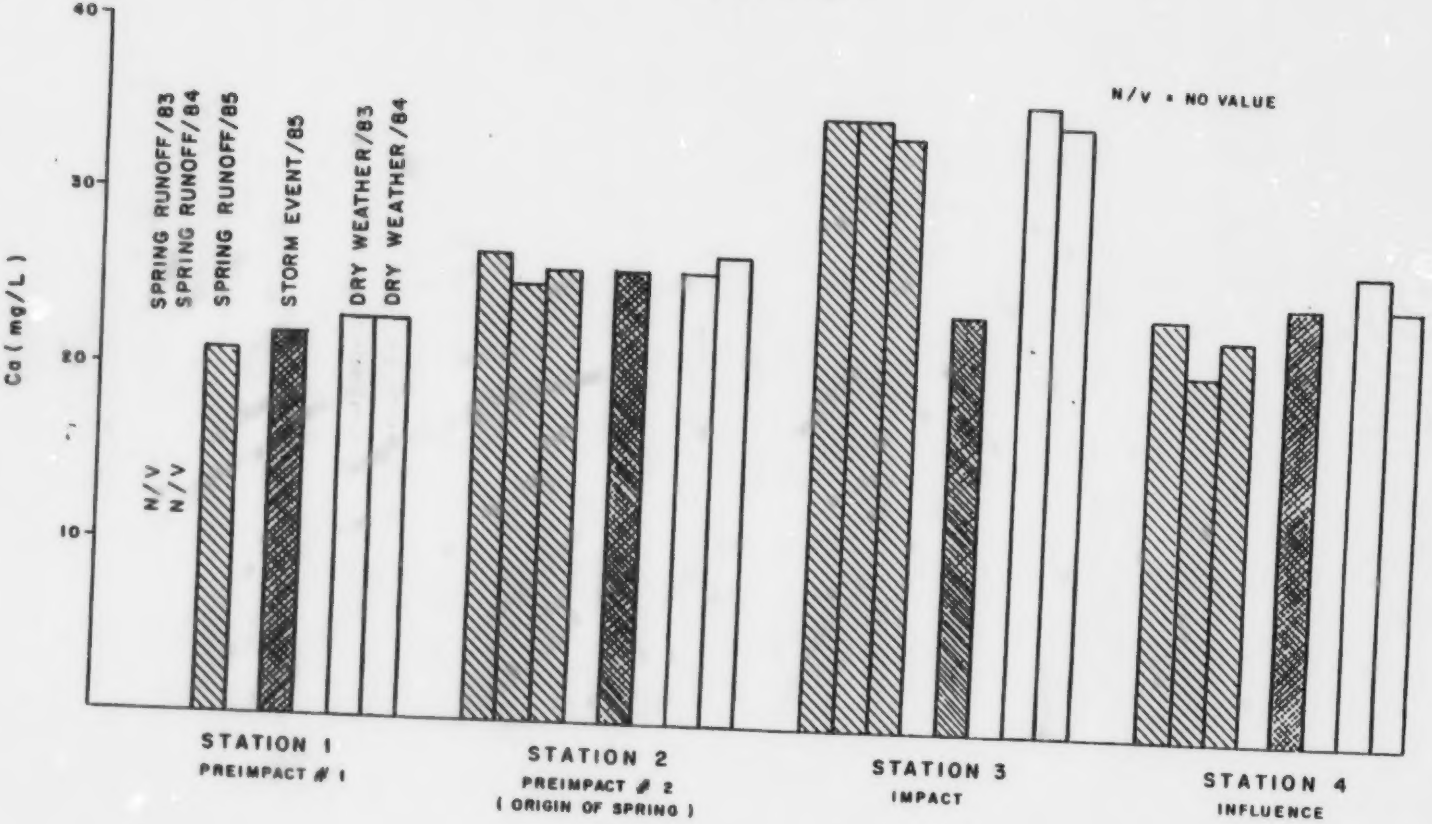
FIGURE 5.6



DISTRIBUTION OF TOTAL DISSOLVED SOLIDS

PALMER RANCH

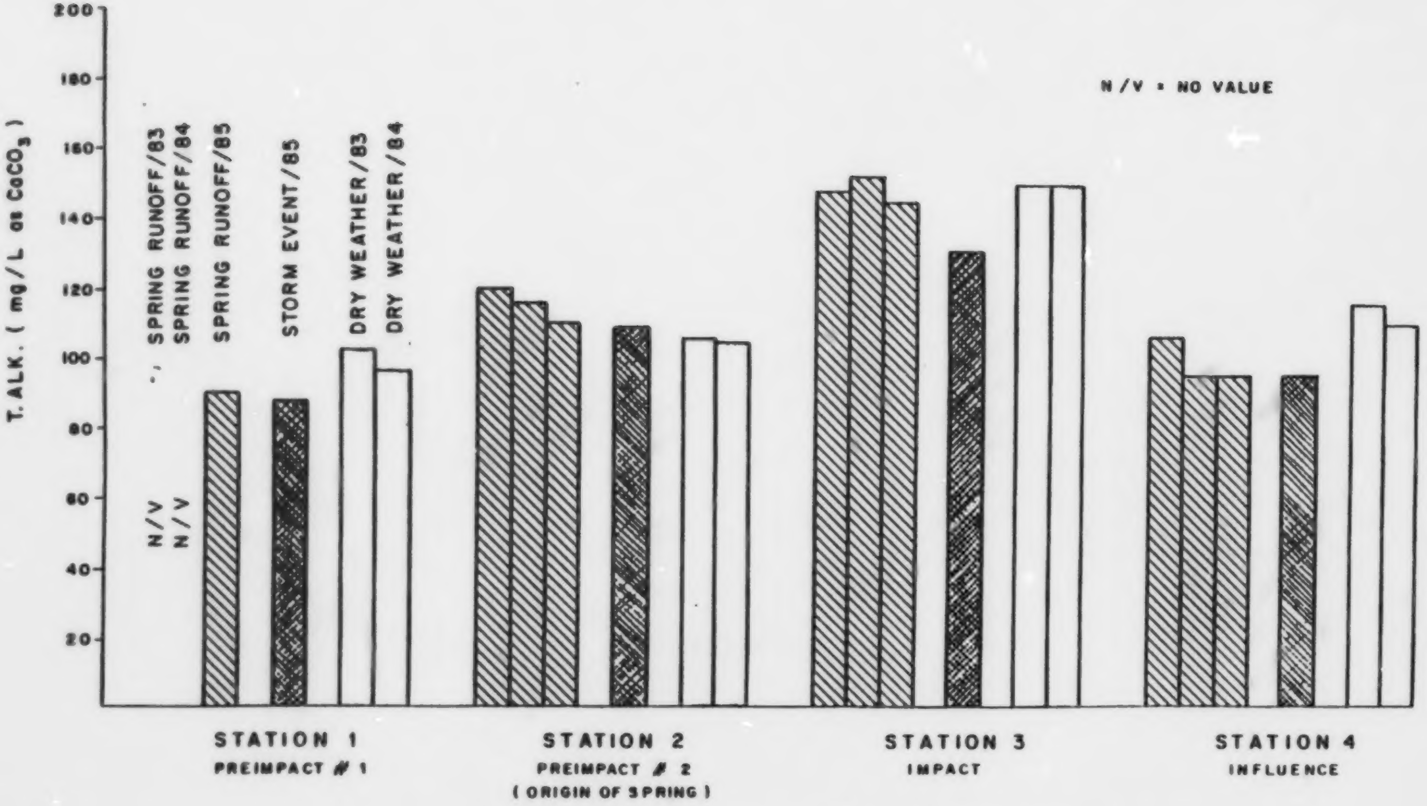
FIGURE 5.7



DISTRIBUTION OF CALCIUM

PALMER RANCH

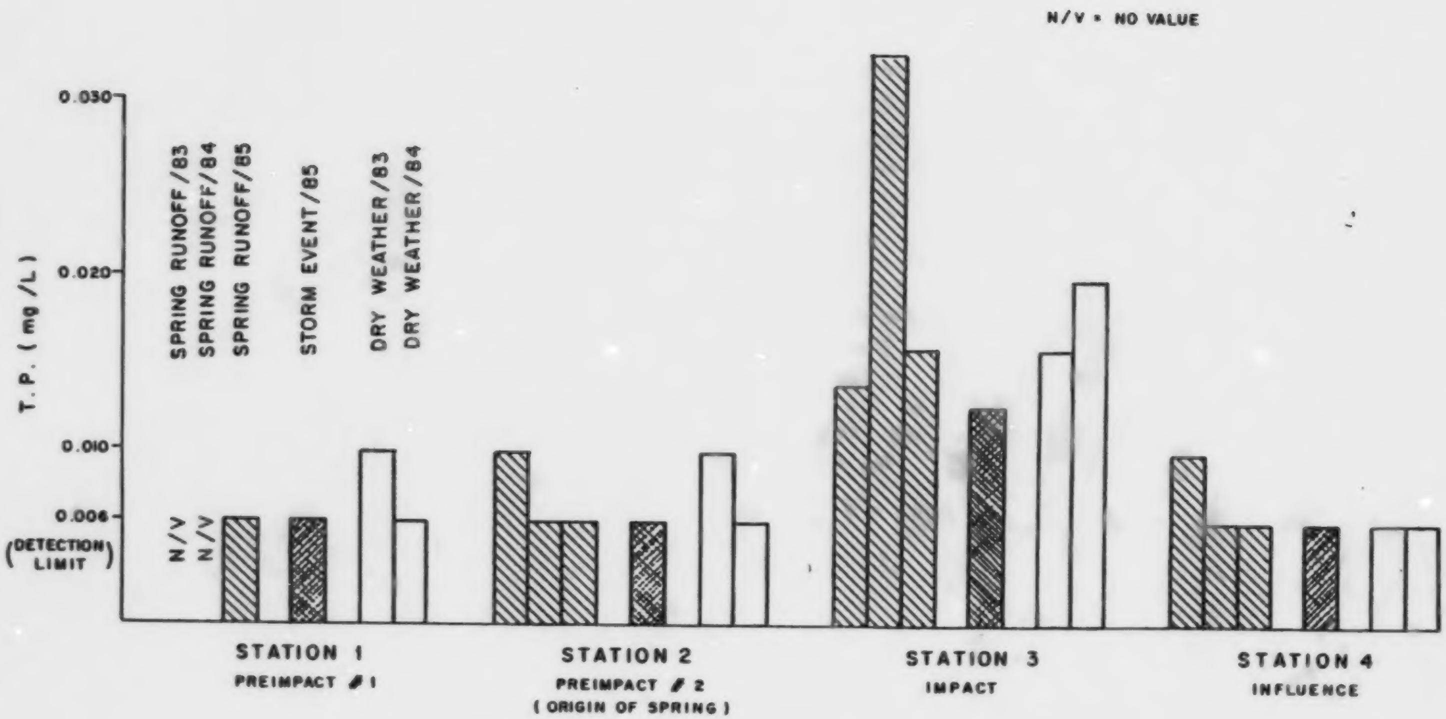
FIGURE 5.8



DISTRIBUTION OF TOTAL ALKALINITY

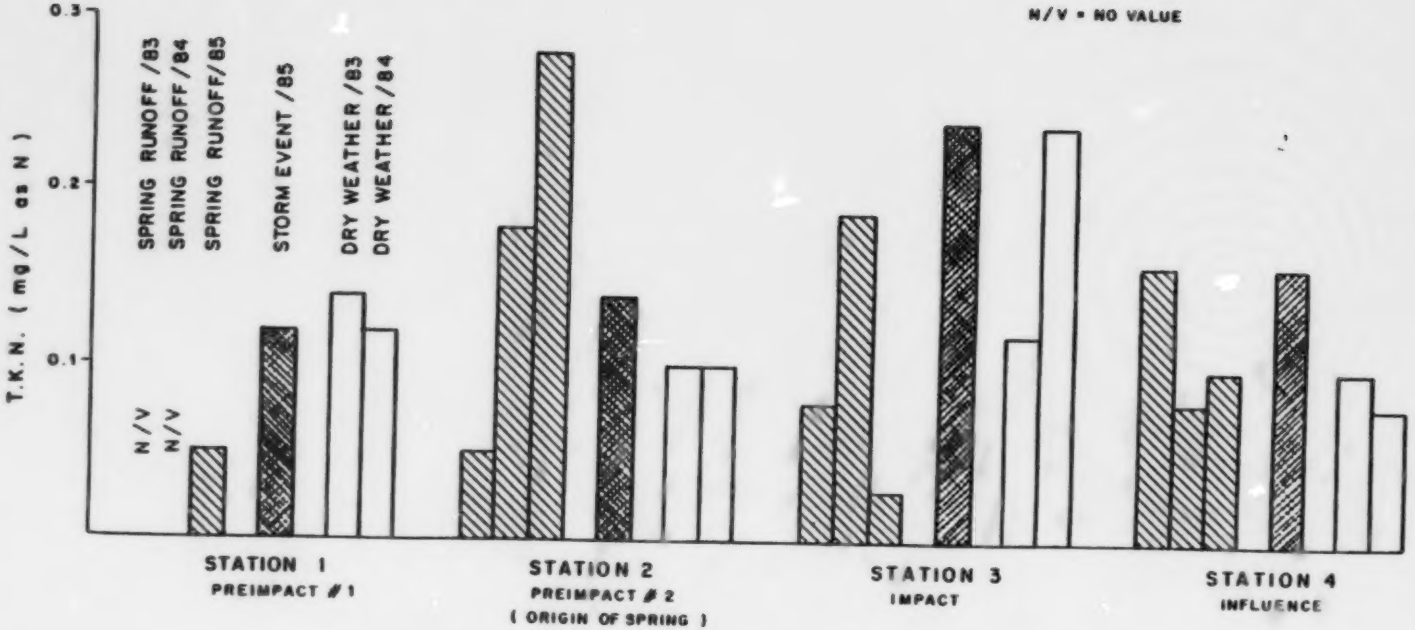
PALMER RANCH

FIGURE 5.9



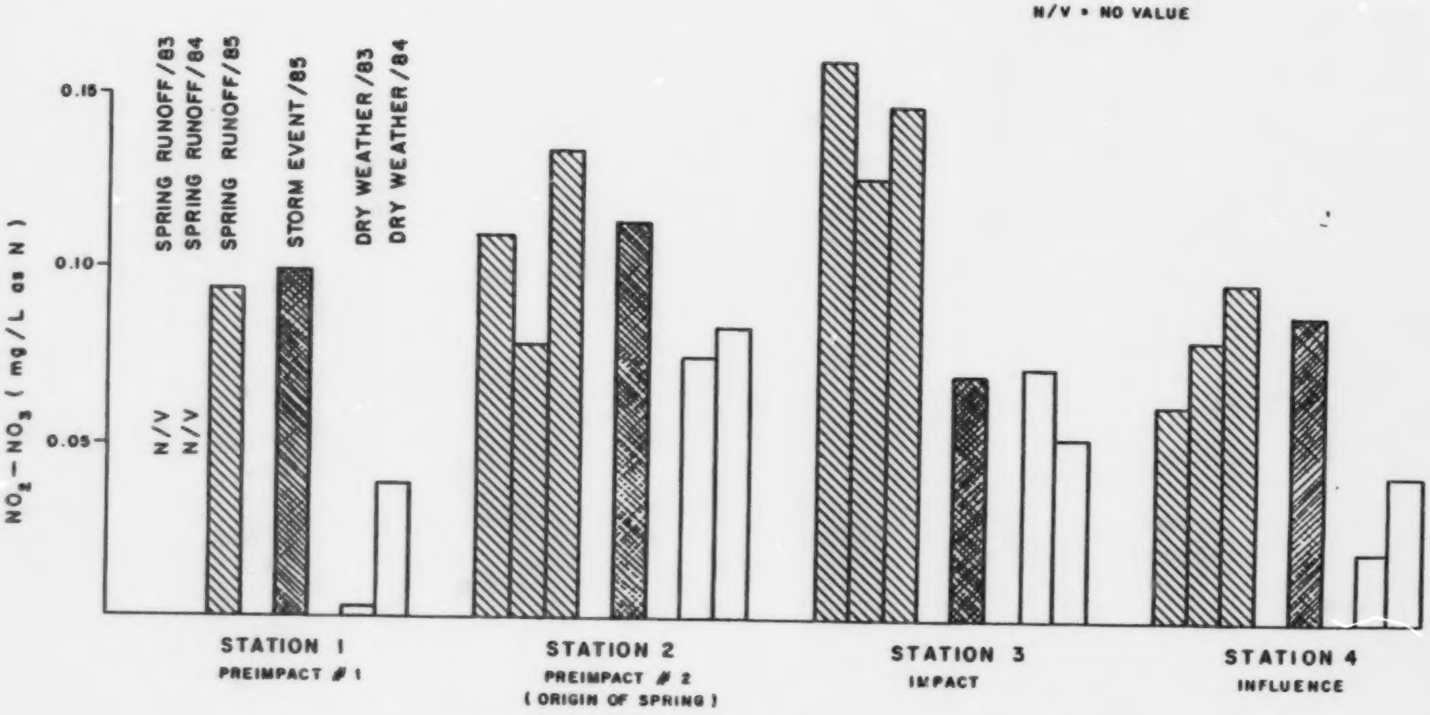
DISTRIBUTION OF TOTAL PHOSPHORUS
PALMER RANCH

FIGURE 5.10



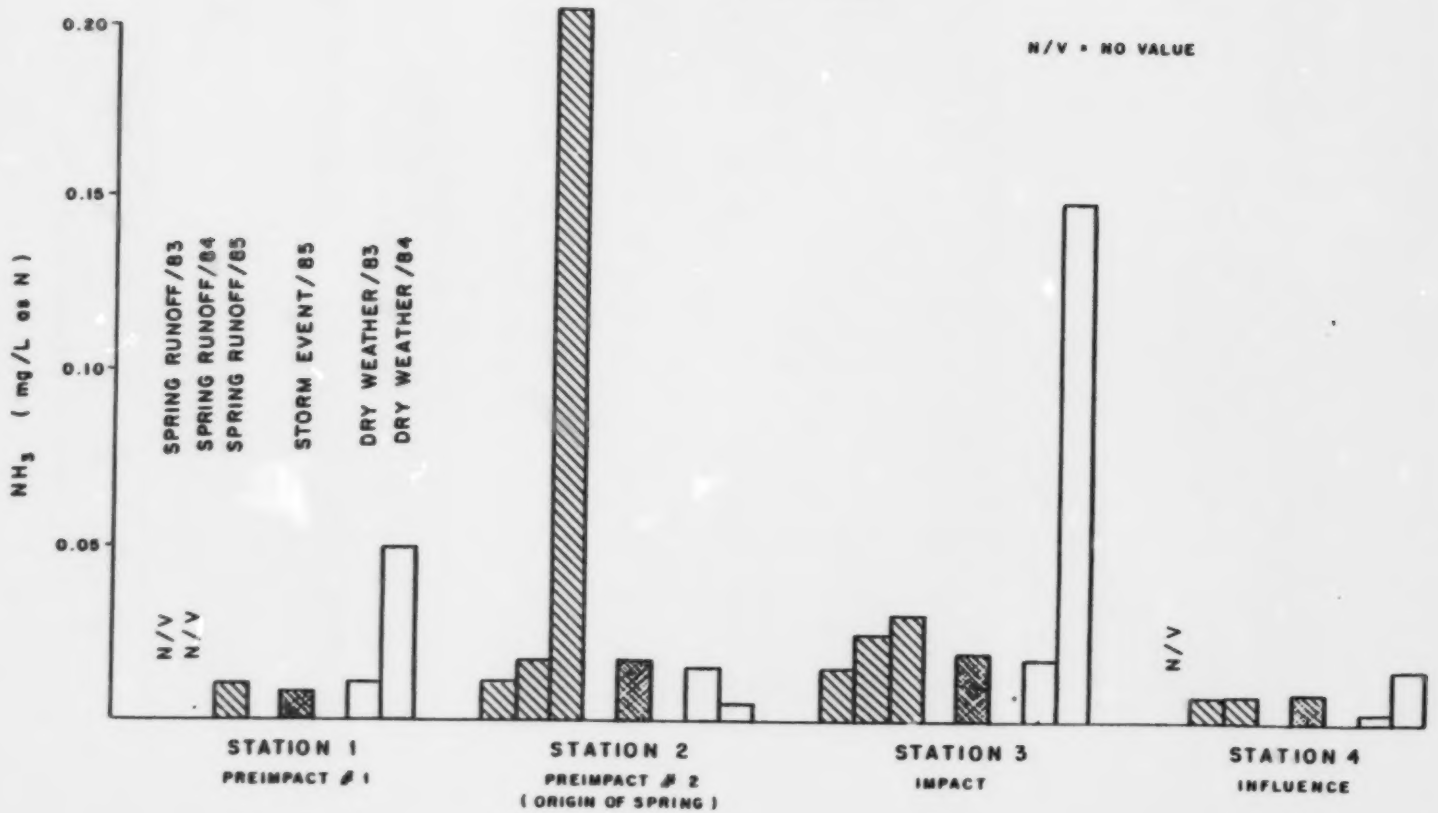
DISTRIBUTION OF TOTAL KJELDAHL NITROGEN
PALMER RANCH

FIGURE 5.11



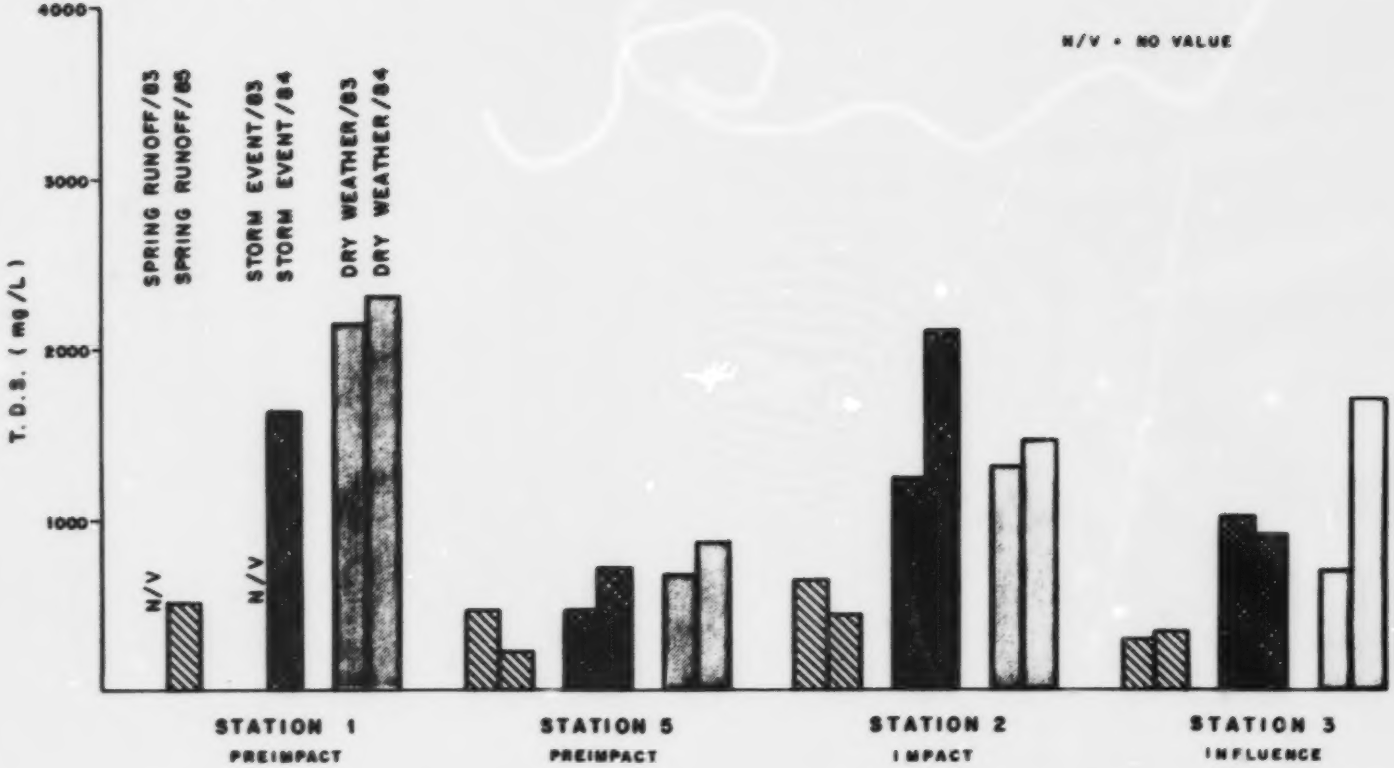
DISTRIBUTION OF NITRATE AND NITRITE
PALMER RANCH

FIGURE 5.12



DISTRIBUTION OF AMMONIA
PALMER RANCH

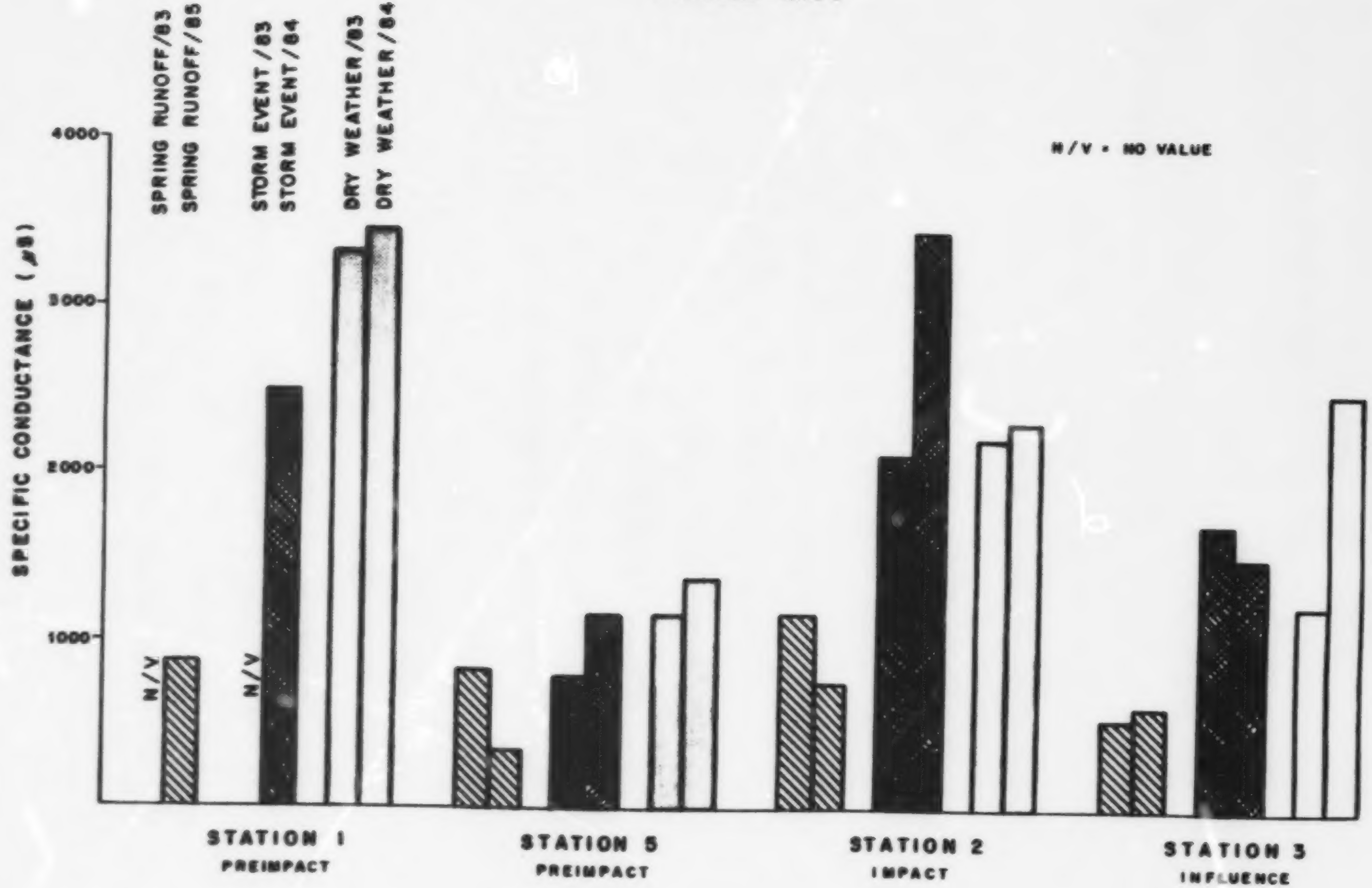
FIGURE 5.13



DISTRIBUTION OF TOTAL DISSOLVED SOLIDS

ADAMS RANCH LTD.

FIGURE 5.14



DISTRIBUTION OF IONIC SPECIES

ADAMS RANCH LTD.

iii) Nutrients

The nutrient concentrations in all collected samples were relatively high in value. Although the surface-water collection sites appeared to be eutrophic, no significant contribution could be assigned to the feedlot.

iv) Metals

Concentrations of heavy metals in the collected samples were low and essentially constant. Except for iron and manganese, concentrations of metals were at, or near, detection limits.

(c) Wes Yanke Ranch, Medicine Hat

Generally, in all events and at all stations no significant feedlot impact on the chemical parameters was noted. Examples of selected parameters are illustrated in Figures 5.19, 5.20, and 5.21.

(d) Adams Ranch Ltd., Czar

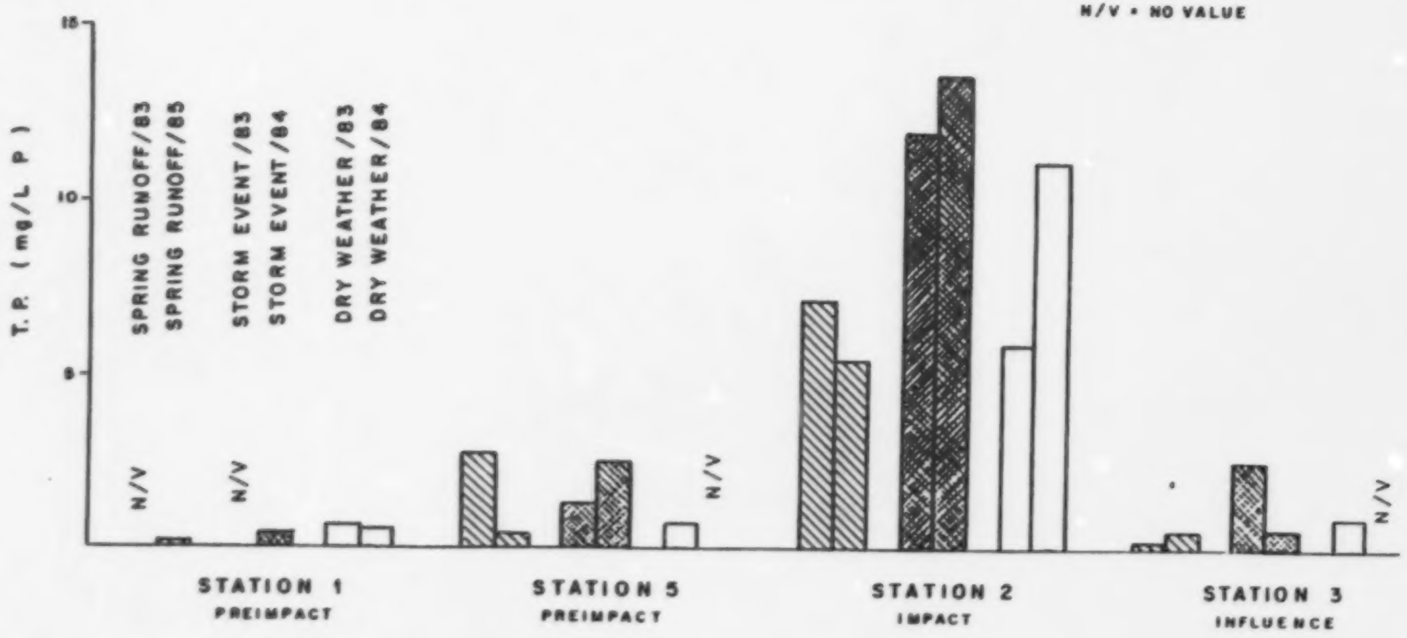
i) Physical Parameters

A minimal impact of NFR was observed. The remaining physical parameters provided no obvious contribution or affect from the feedlot (Figure 5.13).

ii) Major Ions

There was no significant impact on any of the major ions (Figure 5.14). The topsoil in the area appeared to be poorly drained. Ion concentrations in the receiving waters increased with increased precipitation. The impact of the feedlot on the major ion concentrations in the surface water was inconclusive.

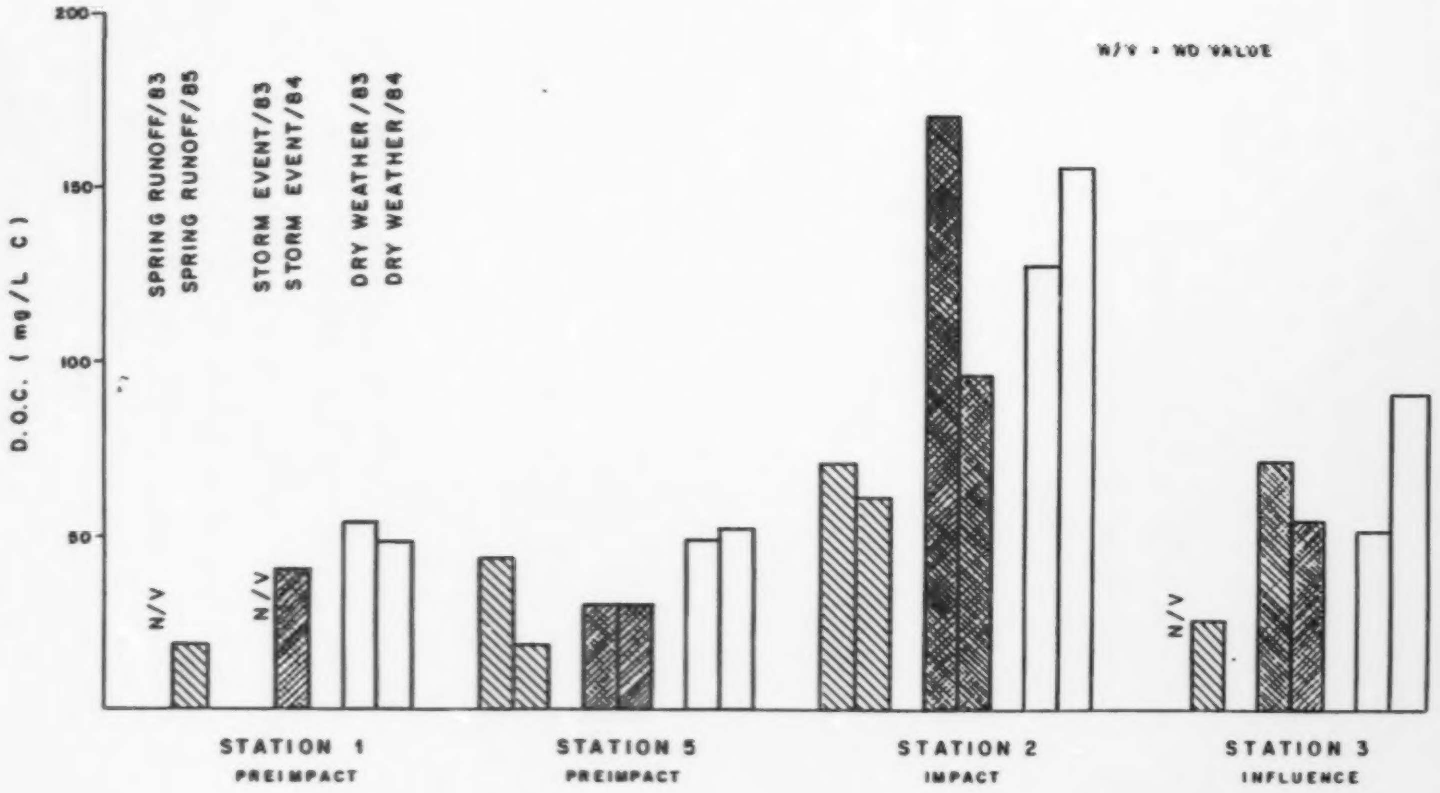
FIGURE 5.15



DISTRIBUTION OF TOTAL PHOSPHORUS

ADAMS RANCH LTD.

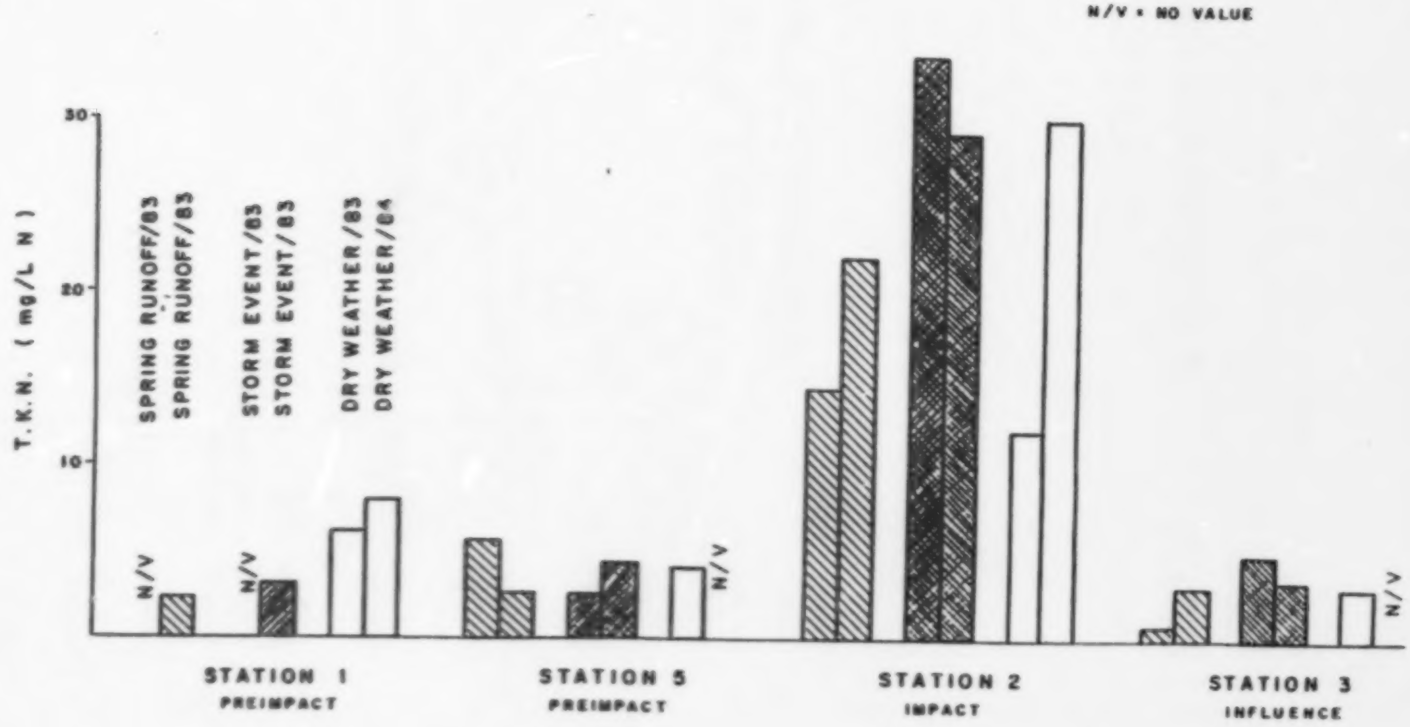
FIGURE 5.16



DISTRIBUTION OF DISSOLVED ORGANIC CARBON

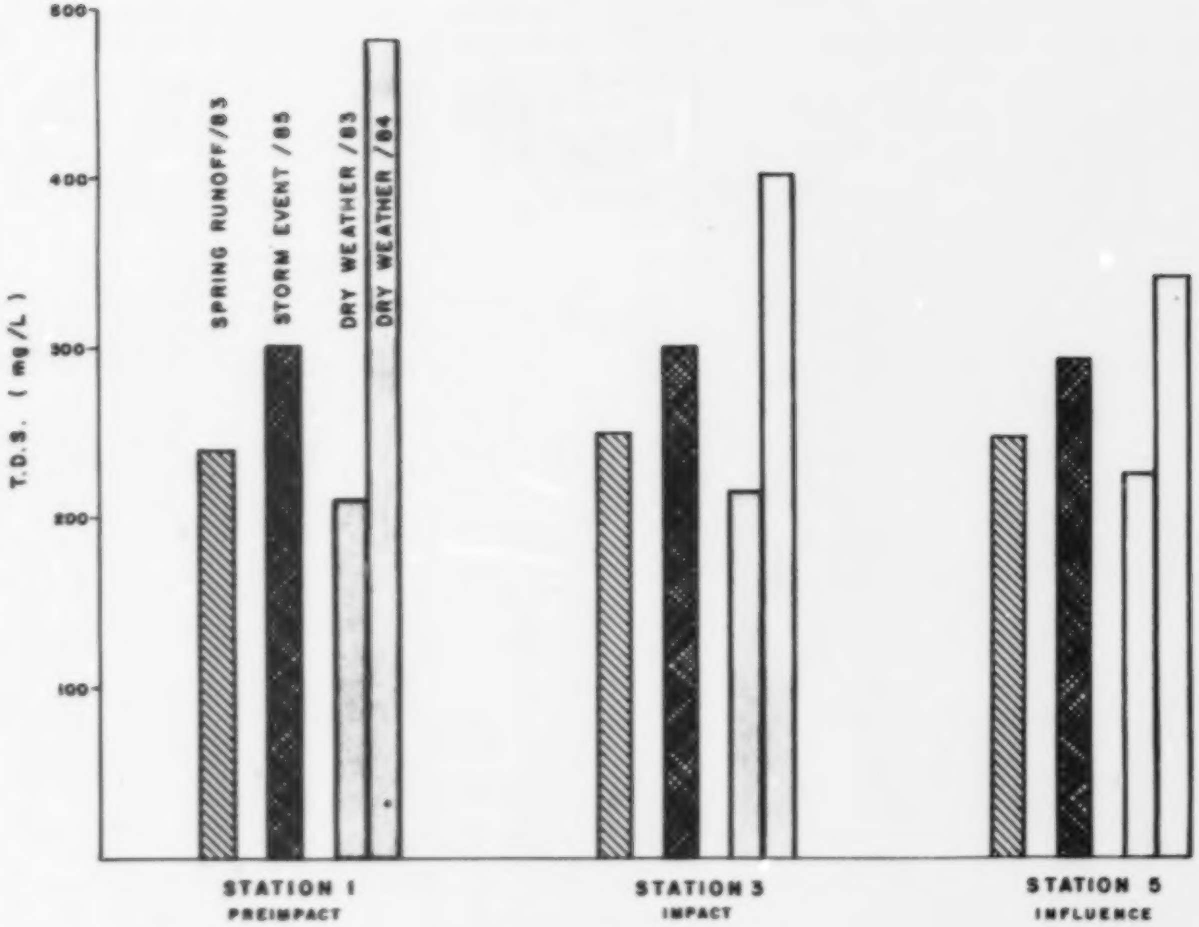
ADAMS RANCH LTD.

FIGURE 5.17



DISTRIBUTION OF KJELDAHL NITROGEN
ADAMS RANCH LTD.

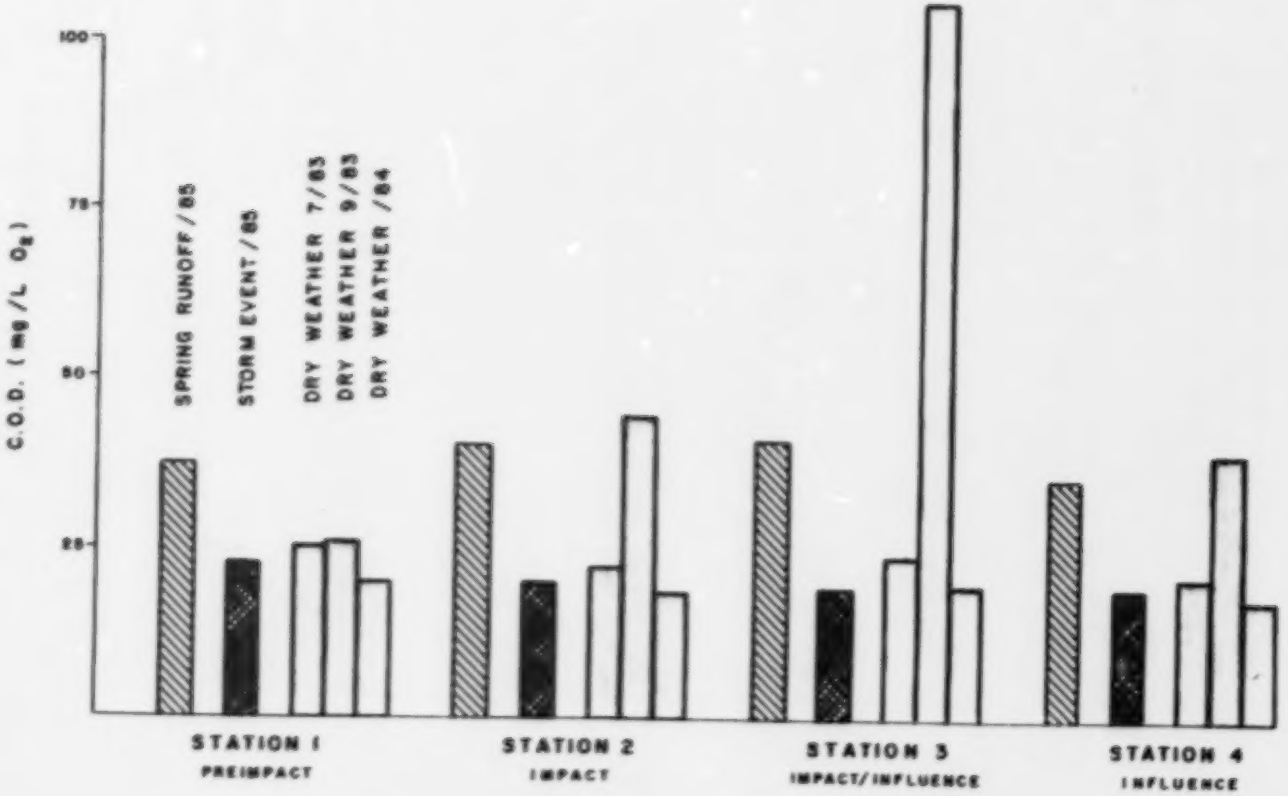
FIGURE 5.18



DISTRIBUTION OF TOTAL DISSOLVED SOLIDS

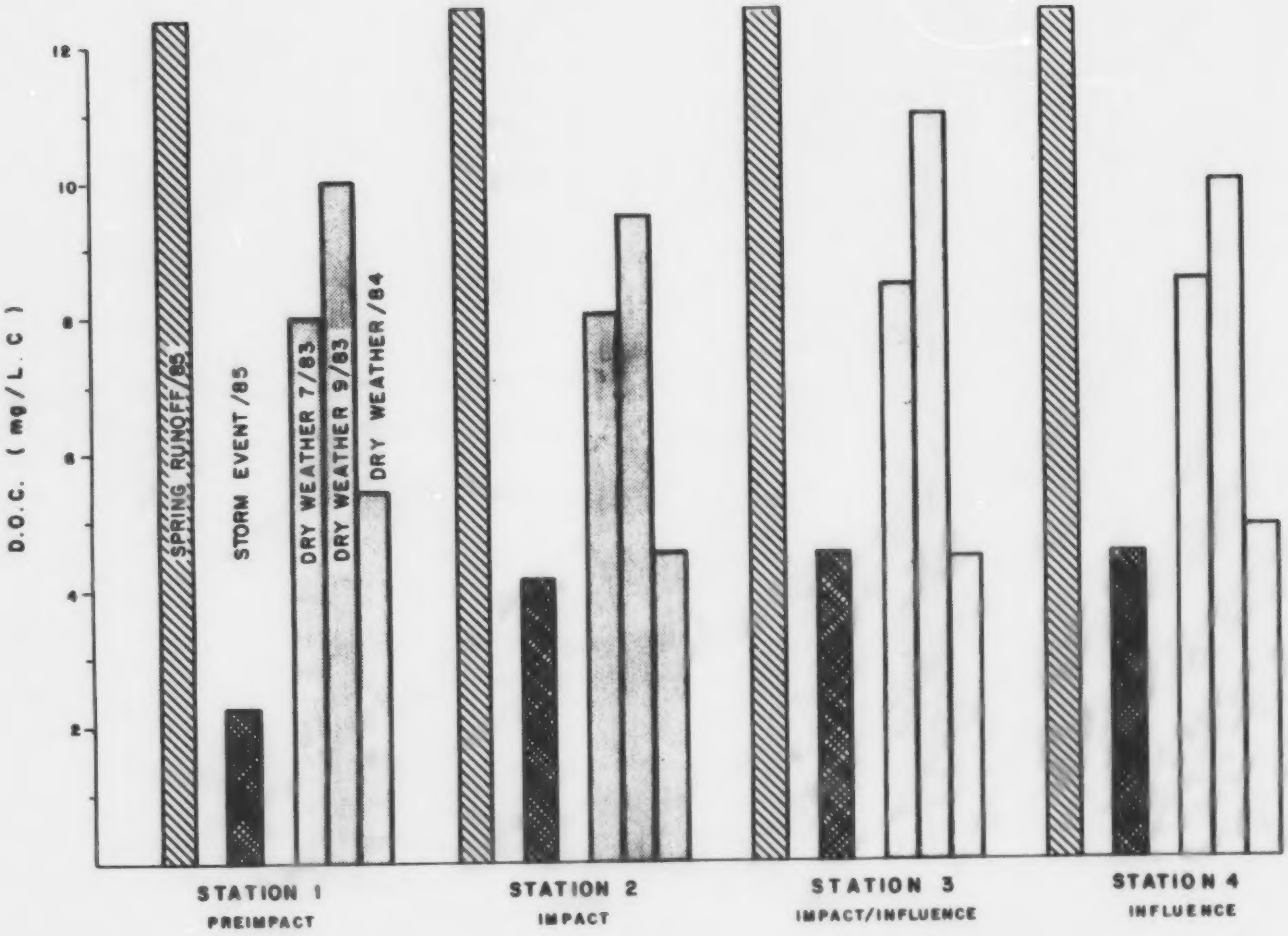
PRIME FEEDERS LTD.

FIGURE 5.19



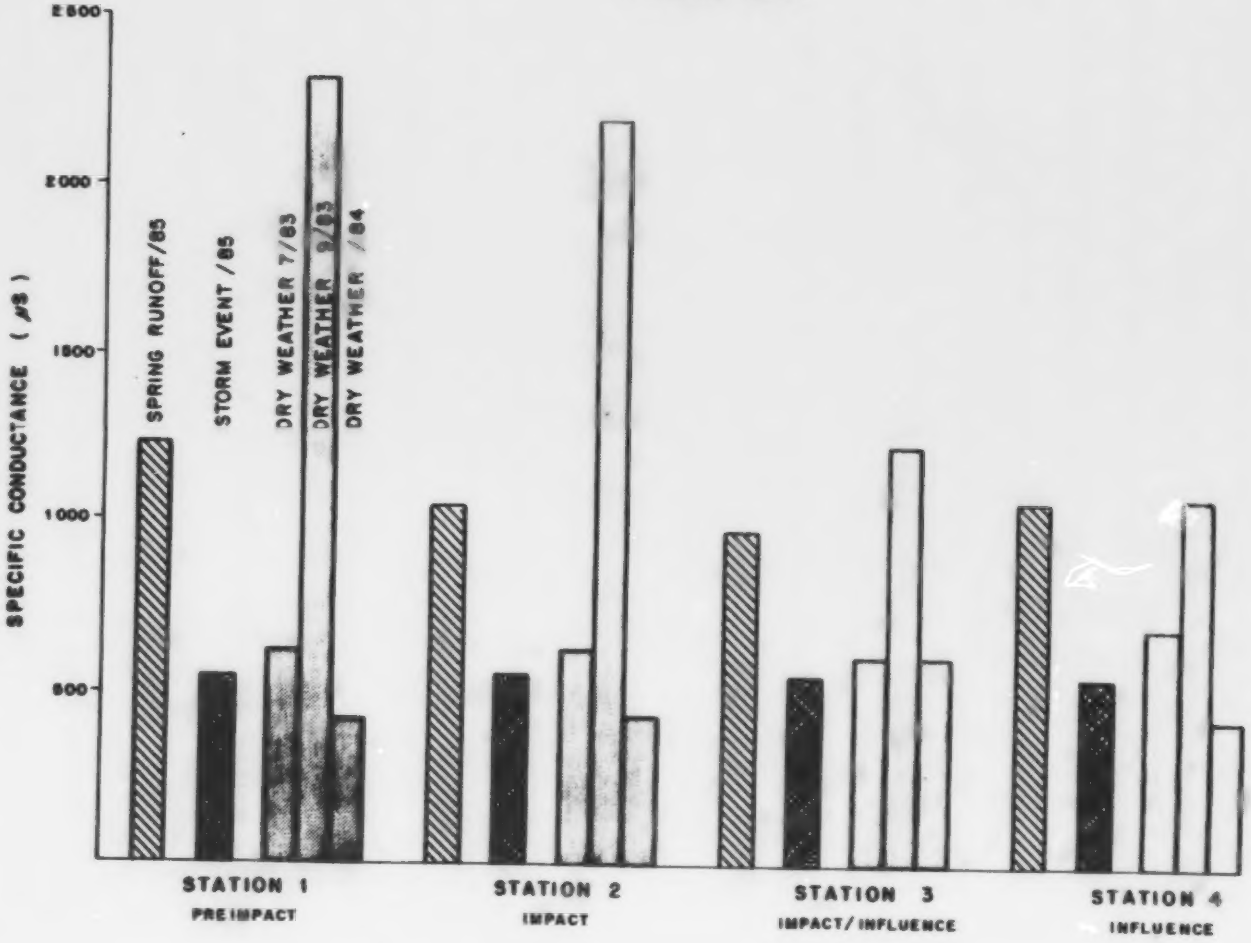
DISTRIBUTION OF CHEMICAL OXIDATION DEMAND
WES YANKE RANCH

FIGURE 5.20



DISTRIBUTION OF DISSOLVED ORGANIC CARBON
WES YANKE RANCH

FIGURE 5.21



DISTRIBUTION OF IONIC SPECIES
WES YANKE RANCH

iii) Nutrients

A marked impact was noted for TP, DOC, NO_2+NO_3, NH_3, and TKN (Figures 5.15, 5.16, and 5.17), while the remaining nutrient data were essentially constant. The nutrient levels were more predictable than the concentrations of major ions. The Shorncliffe Lake headwaters (Station 1) contained low concentrations of nitrogen, phosphorus and carbon relative to the slough (Station 2) and Ribstone creek (Station 3). In contrast, the nutrient concentrations were highest in the slough, which was located at the base of the feedlot. For example, the nutrient concentrations in the slough were generally one to two orders of magnitude higher than those measured upstream on Ribstone Creek. The impact of these high-nutrient concentrations from the slough on Ribstone Creek, however, appeared to be negligible.

iv) Metals

No impact was noted on any of the metal parameters.

5.3 Statistical Analyses

(a) Distance-Decay Model

The changes in microbial counts from the impact station to the subsequent post-impact sampling-stations were studied by the distance-decay model. This approach was used because the location of sampling stations was fixed for all surveys for each feedlot. Therefore, the distance between sampling stations remained constant throughout the study. The advantage of this technique is that apart from the knowledge of distance between sampling stations and microbial counts at these stations, no further information on physicochemical properties of water bodies is required to study the fate of microorganisms as they pass through the stream of water.

As described in the Materials and Methods Section (3.3.3), the distance-decay model (13) was fitted to the pooled data for all surveys for each feedlot, and the calculated distances in metres from the main impact station to various other sampling stations for each feedlot are given in Table 5.1. Data from the pre-impact station were not included in the analysis, and the distance at the impact station (Station 2) of each feedlot was considered to be zero. Measurements of distance were only approximate. In some cases, as in Palmer Ranch, there was more than one source of impingement.

Distance-decay graphs for all data from the four feedlot sites are provided in Figures 5.22, 5.23, 5.24, and 5.25. In most cases, they show a steady decline of microbial counts. For example, at Prime Feeders Ltd., the distance-decay coefficients, based on all the data from four surveys, were significant ($P \leq 0.01$) for HPC 35, HPC 20, ANA, FUNGI, and FS, but were not significant for TC and FC. By extrapolating the distance-decay equation, it is possible to calculate the travel distance required to reduce the microbial count to 1 at Prime Feeders Ltd. For example, it would take 4.55 km from the impact station for the FUNGI count to be reduced to 1. For FC and TC counts, which had non-significant distance-decay coefficients, the distance travelled would not be sufficient to reduce these counts. This type of extrapolation must be done with caution and it must be assumed that the conditions affecting microbial counts are similar in both non-sampling, extrapolated zones and the actual sampling zone.

Table 5.1. Distance in metres from the impact station to various other sampling stations[1]

FEEDLOT	PRE-IMPACT		INFLUENCE/POST-IMPACT			
	1	1[2]	3	4	5	6
Adams Ranch Ltd.	3050	-	700	1350	4050	6800
Prime Feeders Ltd.	490	-	240	740	1415	1945
Palmer Ranch	180	20002[2]	320	1370	2300	-
Wes Yanke Ranch	1100	-	715	1235	2735	-

---

[1] Station 2 was the impact station with distance = 0.

[2] Palmer Ranch feedlot had two Pre-Impact Stations.

FIGURE 5.22

DISTANCE DECAY MODELS FOR ALL DATA FROM PRIME FEEDERS LTD.

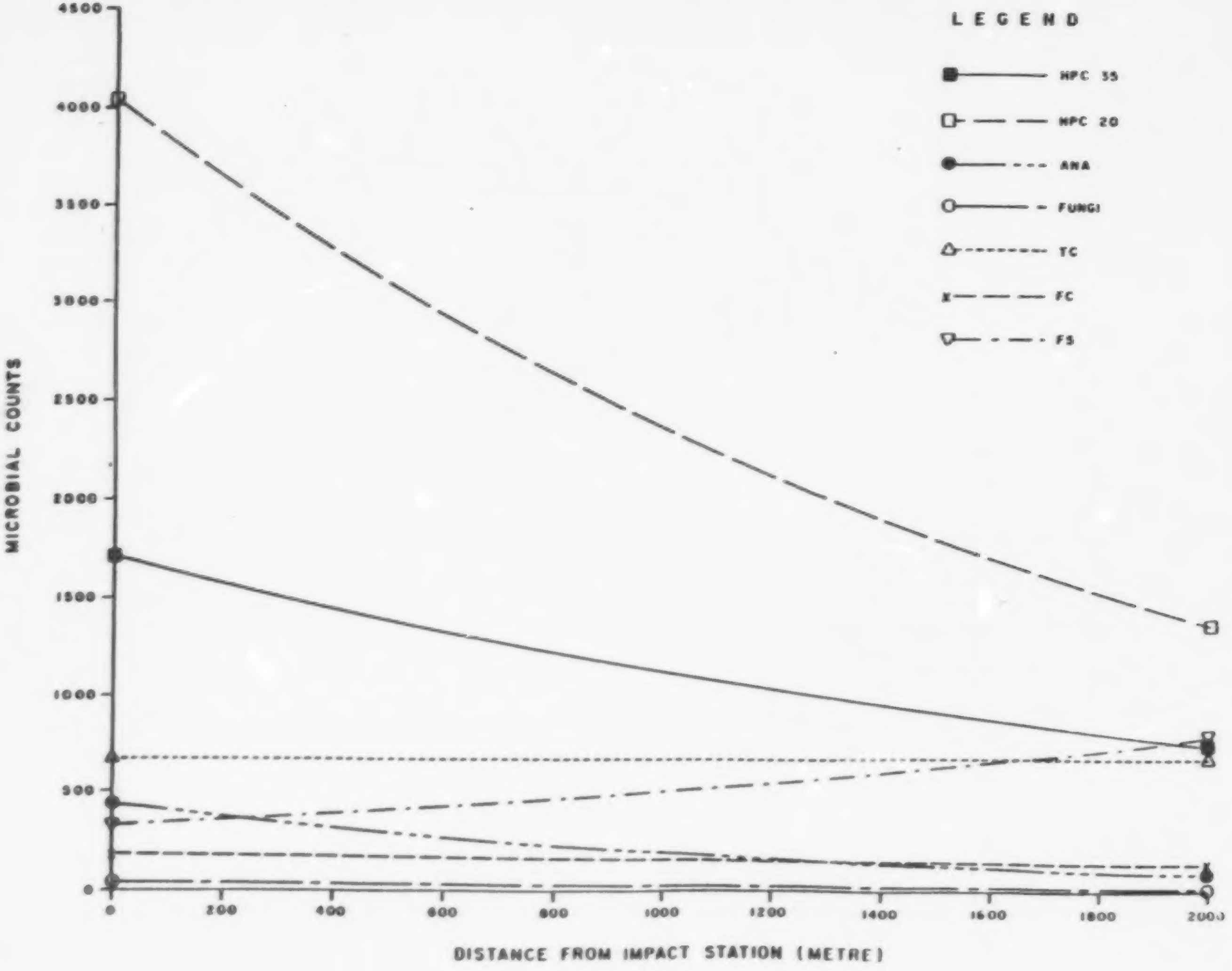


FIGURE 5.23

DISTANCE DECAY MODELS FOR ALL DATA FROM PALMER RANCH

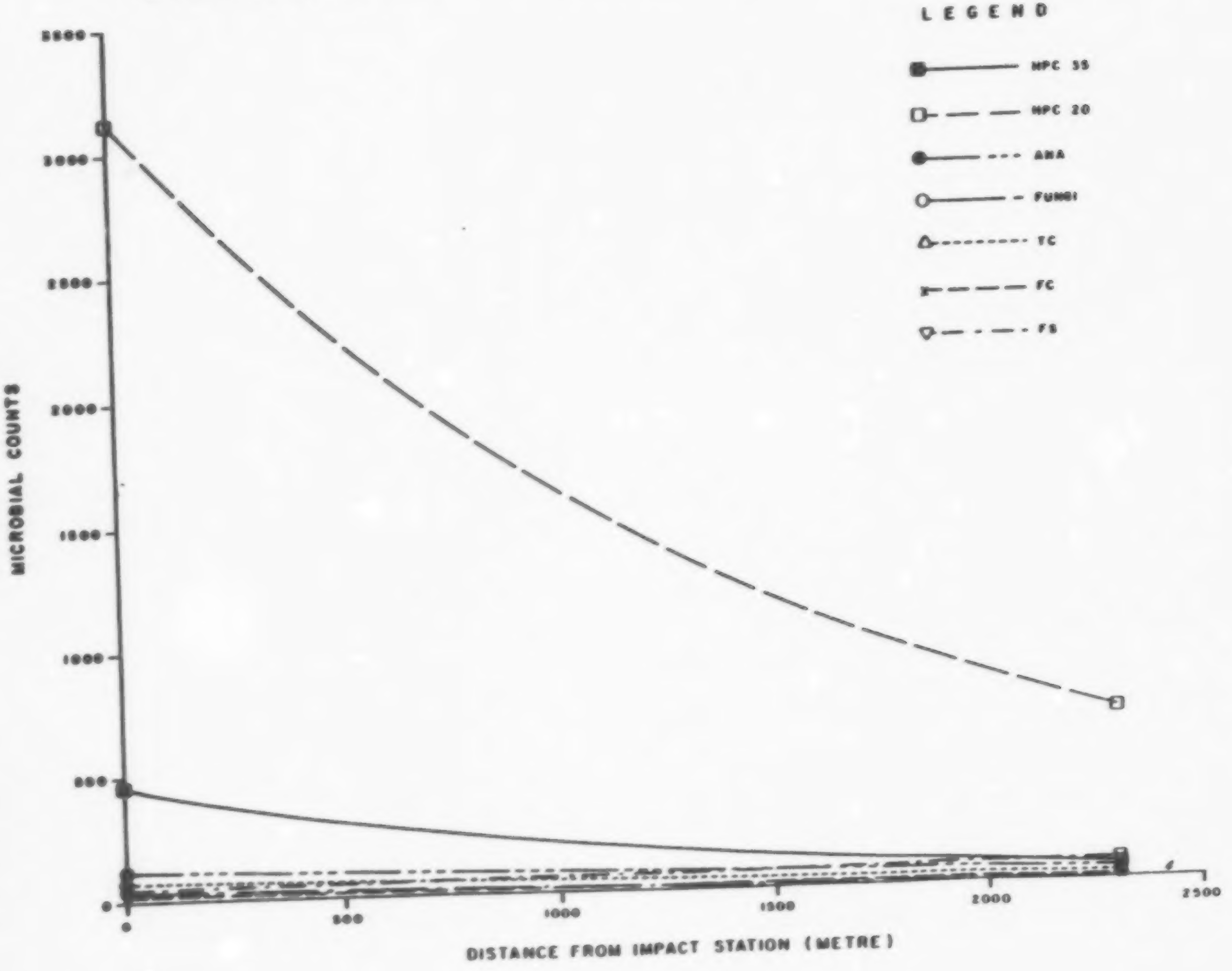


FIGURE 5.24
DISTANCE DECAY MODELS FOR ALL DATA FROM WES YANKE

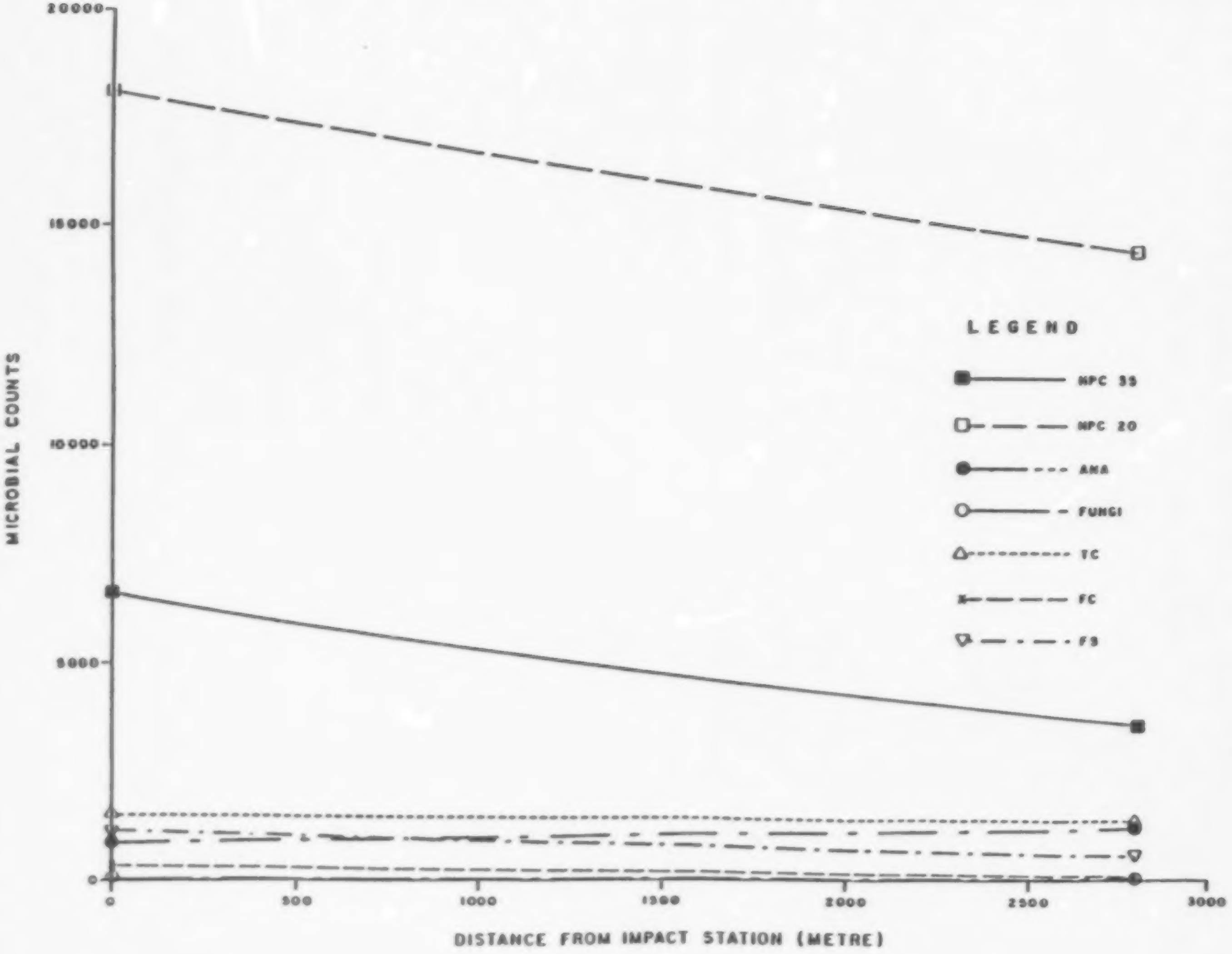
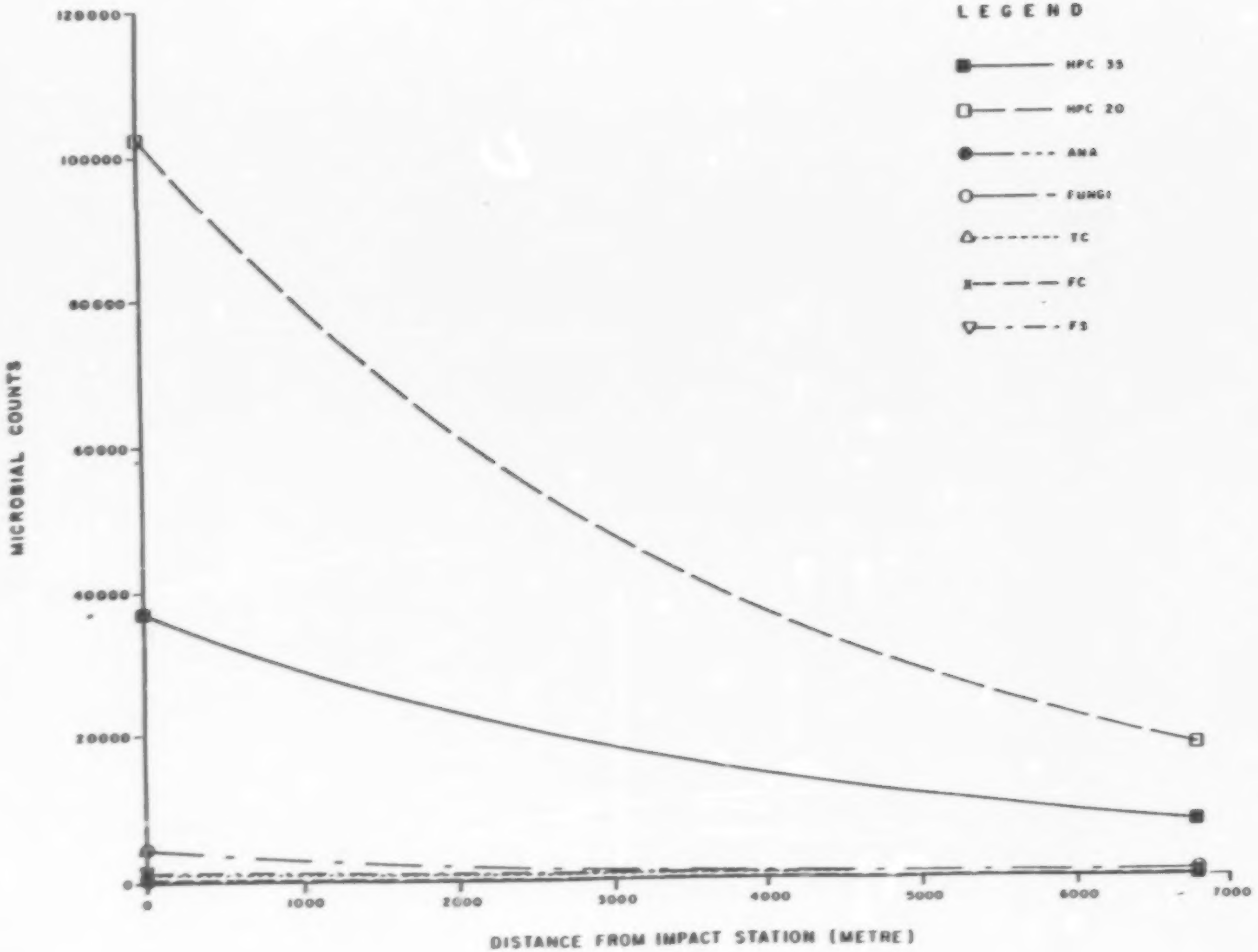


FIGURE 5.25

DISTANCE DECAY MODELS FOR ALL DATA FROM ADAMS RANCH LTD.



An examination of the R^2 values (coefficient-of-determination) can also reveal the effect of distance on the fate of microbes. R^2 values ranged from 0 to 42.03%, but most values were less than 18%. This indicated that only a small amount of variation in microbial counts could be attributed directly to the distance between sampling-stations. Low R^2 values were also observed for other feedlots. This means that the distance-decay model is generally not an effective way to describe the fate of microorganisms during downstream transport.

In some cases, however, such as the FS counts for Prime Feeders Ltd., the distance-decay coefficient was found to be statistically significant ($P \leq 0.01$) with a positive value (Figure 5.22). This indicates that apart from the impact station, there were other sources of impingement of FS within the sampling zone. This relationship is shown by a positive slope in the graph.

The distance-decay relationships described here are only applicable to the feedlots under study. Based on the R^2 values and Standard Errors of the predicted equations, distance-decay equations are not satisfactory in predicting the reduction in microbial counts based on the distance travelled through water. Other physicochemical properties of water must be investigated to create a realistic model of the fate of microoganisms.

(b) Multiple-Regression Model

As stated in the Materials and Methods Section (3.3.4), a backward-elimination, stepwise-regression approach was used to develop predictive equations. In this stepwise approach, variables were added one by one to the model, with the condition that F-statistics for a variable to be added must be significant at a prespecified level ($P \leq 0.01$). After a variable was added, it was tested for its significance at this prespecified level and only those variables found to be significant at $P \leq 0.01$ were permitted to remain in the final equations. This small significance level was used as it has been found that when many significance tests are performed, each at a level of 5%, for example, the overall probability of rejecting at least one true null hypothesis is much larger than 5%. To guard against including any variables that do not contribute to the predictive power of the model, it is recommended that a very small significance level, such as 1%, be specified.

For stepwise-regression analysis of the individual survey data, however, a $P \leq 0.05$ significance level was used because most variables failed to show any significant effect at the $P \leq 0.01$ level as the result of a small number of observations. The results of stepwise-regression analysis of the individual survey data for each feedlot are presented in the unpublished data appendix.

Additional analyses were performed on the pooled data (data from all conducted surveys) for each of the four feedlots. Results of stepwise-regression analyses from the pooled data (all parameters) for each feedlot are presented in the Results and Discussion Section (4.4) along with a listing of significant ($P \leq 0.01$) independent variables. A large number of independent variables was found to be significant ($P \leq 0.01$) in the pooled data analysis. This probably results from using a large number of observations in the pooled data set, which led to degrees of freedom for the error mean squares that were quite high, thereby causing the test of significance to be more sensitive. However, the relative contribution of each independent variable on the variability in microbial counts was different and depended upon the magnitude of the coefficient in standardized units relative to others in the model.

The frequency of occurrence of significant independent variables is listed in Table 5.2. It is evident that variables such as TEMP, pH, NFR, NO_2+NO_3, FR, TURB, DIST and SCOND (which occur at least in 3 surveys out of 4) played a major role and significantly influenced the microbial densities. Therefore, these eight variables should be emphasized for future monitoring and feedlot-impact assessment studies of this nature. Moreover, from the range of R^2 values, it is evident that about 73 to 99% of the variation in microbial counts could be attributed to the significant independent variables in this model. The observed range of R^2 values is typical in a natural biological system, as it is almost impossible to account for 100% of the variation.

The predictive equations as developed in this study are valid only for the feedlots for which they were developed, and only for the conditions similar to those encountered during the course of this study. Any extrapolation to other feedlots or different environmental conditions is not recommended.

Table 5.2. Frequency of occurrence of significant independent variables in multiple-regression equations. (Based on summary of data for all feedlots for all surveys)

	INDEPENDENT VARIABLES						
OCCURRENCE	HPC 35	HPC 20	ANA	FUNGI	TC	FC	FS
In All 4 Feedlots				TURB			
In 3 Out of 4 Feedlots	TEMP pH	NFR NO_2+NO_3	TEMP NO_2+NO_3	FR	DIST TURB SCOND	R7D	DIST pH SCOND
In 2 Out of 4 Feedlots	DIST NH_3 NO_2 OP	DIST TURB pH SCOND FR NH_3 BOD	TURB DOC NO_2 OP R3D R7D	DO_2 pH NFR DOC NO_2 NO_2+NO_3	NO_2 NO_2+NO_3 R2D R7D	DIST SCOND TP	TEMP TURB FR NH_3 COD NO_2 OP R7D
In Only 1 Feedlot	TURB FR NFR PARTN DOC BOD NO_2+NO_3 R1D	DO_2 PARTN TKN PARTC DOC NO_2 OP R3D	DIST DO_2 SCOND FR TDS NFR PARTN TKN	DIST TEMP PARTC TP COD BOD R7D	DO_2 pH PARTC BOD R3D	pH FR TDS PARTN TKN DOC COD R3D	NFR PARTC DOC TP BOD NO_2+NO_3 R1D R3D
			PARTC TP R1D R2D			NO_2+NO_3 OP	
% R^2 Range	66.46 to 87.97	89.91 to 97.73	60.81 to 97.78	90.54 to 94.81	85.75 to 97.48	80.07 to 98.28	88.90 to 98.92

6.0 SUMMARY AND CONCLUSIONS

Thirteen feedlots in Alberta were initially surveyed and assessed for suitability as candidate study sites. Of these, four feedlots were selected for detailed studies according to a set of criteria designed to provide information pertinent to study objectives and to optimize findings. Twenty-one surveys, consisting of seven spring-runoff, five storm-event and nine dry-weather surveys, were conducted at these sites during a three-year (1983-85) study period to provide information on the impact of feedlot wastes and associated runoff on the quality of recieving surface waters. Major findings based on all microbiological, physical, chemical and statistical data are summarized below for each feedlot.

(a) Palmer Ranch, Waterton

Microbiological levels were generally very low in receiving waters and were influenced to various degrees by survey conditions. As an example, during the storm-event survey, a significant water-quality impact was evident because the levels of FC were three times higher at the impact station (Station 3) than the maximum recommended level according to the guidelines for Canadian/Alberta recreational water quality (2, 6). These levels did not decrease to pre-impact levels at all of the downstream stations. In contrast, during the spring-runoff and dry-weather surveys, microbial densities were sufficiently small to allow the pre-impact levels to be reached at Stations 4, 5, and 6 during the downstream transport from the impact station.

Levels of nutrient parameters, such as total Kjeldahl nitrogen (TKN), total phosphorous (TP) and dissolved organic carbon (DOC), were also very low. The TKN levels, however, were elevated at the impact station (Station 3) during the storm-event survey. Specific conductance was consistently higher at the impact station than at the pre-impact stations, indicating that some dissolved solids were being contributed by the feedlot.

The adverse water-quality impact of wastes and associated runoff at this feedlot, although clearly demonstrated, was probably minimized by the fast-flowing nature and relatively large volume of the Waterton River.

(b) Prime Feeders Ltd., Fort Macleod

Microbial levels were generally low, but greater than those observed at Palmer Ranch. Although the densities of TC and FC at the pre-impact, impact and post-impact stations exceeded the guidelines for Canadian/Alberta recreational water quality (2, 6), during the storm-event surveys, the impact on water quality was not clearly discernible. This resulted from levels of these parameters that were generally similar at all stations. During the spring-runoff surveys when counts at the pre-impact station were low, however, levels of TC, FS and heterotrophic bacteria (HPC 20°C, HPC 35°C) increased substantially at the impact stations (Stations 2 and 3), indicating some affect from feedlot runoff. A return to pre-impact levels for these parameters occurred 0.5 km downstream of the impact zone (at Station 4).

Nutrient levels were higher than those observed at Palmer Ranch, and were above ambient levels at all stations. There was no evidence of any adverse water-quality impact, although a slight contribution of TKN from the feedlot was indicated.

(c) Wes Yanke Ranch, Medicine Hat

Microbial counts at this feedlot were extremely variable, particularly those of TC, FC and FS, which ranged from low to very high during spring-runoff and dry-weather/storm-event surveys, respectively. As an example, during the storm-event survey, densities of TC, FC, and FS were significantly higher at the impact station (Station 2) than at the pre-impact station, and their levels at all stations exceeded [illegible]idelines for Canadian/Alberta recreational water quality (2, 6) by a factor of two to nine. The densities of these organisms decreased somewhat, but then increased again during further downstream transport (particularly at Station 5). This was probably caused by other non-point sources. During the spring-runoff survey, the levels of selected bacterial parameters increased slightly at the impact station. These densities returned to pre-impact levels, however, (at Station 5), which was 1.25 km downstream from the impact station. The nutrient levels were similar to those found at Prime Feeders Ltd., and were not appreciably influenced by feedlot runoff.

As previously observed at Prime Feeders Ltd., the water quality at Wes Yanke Ranch was substantially impaired, but the extent of contribution by the feedlot runoff was not clearly delineated. This was caused by significant contributions from other non-point sources, both upstream and downstream of the feedlot.

(d) Adams Ranch Ltd., Czar

The highest levels of all microbial parameters and selected nutrient parameters (TKN, TP and DOC) were observed at this site, which reflected the eutrophic nature of receiving waters in this area. The impact of feedlot runoff on levels of selected microbial and chemical parameters in the adjacent slough (impact Station 2) was highly significant during most surveys. This impact, however, was not found to any significant degree in Ribstone Creek (at Stations 3 and 4) because of the slough drainage was slow and limited. The only observed exception pertained to the levels of heterotrophic bacteria (HPC 20°C, HPC 35°C), which were significantly elevated at the Ribstone Creek Station 3 during the spring-runoff survey. The densities, however, decreased to pre-impact levels 5.45 km downstream at Station 6. A slight impact on TKN, DOC, TDS and SCOND levels in Ribstone Creek was also suggested during some surveys as evidenced by the higher concentrations at Station 3 than at Station 5 (pre-impact station on Ribstone Creek).

At this feedlot, an adjacent slough served as a "catchment pond", where levels of all microbial parameters remained high during most surveys. Measuring the effect of these elevated parameters on groundwater quality was not an objective of this study, but further investigation of this aspect may provide some relevant information about the potential affects on groundwater quality.

In addition to the foregoing specific information for each feedlot, some general observations and conclusions were also drawn, and these are summarized below.

(a) The impact on receiving waters adjacent to the feedlots was variable and tended to be site specific as the result of local hydrological conditions and the unique nature of each feedlot. The data presented in this study, therefore, can only serve as a general guide for the assessment of similar feedlots and should not be extrapolated to other feedlots for determining potential water-quality impact.

(b) Although varying levels of physical parameters, major ions, metals and certain nutrient parameters were encountered, no identifiable impacts were detected in receiving waters at all feedlots. Concentrations of many metals were at the detection level throughout this investigation. Small impacts on the concentrations of TKN, DOC, and TP were observed at some of the feedlots, however.

(c) With respect to microbiological parameters, significant seasonal variations were observed at all feedlots. In particular, hydrological conditions greatly affected microbial densities, as levels of TC, FC, and FS were highest during storm-event surveys at all feedlots, but were generally lowest during spring-runoff surveys. On the other hand, levels of heterotrophic bacteria (HPC 20°C and HPC 35°C) were high during spring-runoff survey (Prime Feeders Ltd., Adams Ranch Ltd.) as well as during storm-event surveys (Palmer Ranch, Wes Yanke and Adams Ranch Ltd.). Furthermore, a small impact on selected microbial parameters was also observed during some dry-weather surveys. This effect varied from year to year and seemed to be influenced by the local weather conditions that preceded sampling.

(d) Results obtained from storm-event surveys conducted only once at each feedlot should be interpreted as indicating a trend only, and should be regarded as not conclusive because findings may change with an increased frequency of storm-event sampling.

(e) Microbial parameters are non-conservative, time dependent and extremely sensitive to environmental variables. As such, microorganisms generally are not transported downstream long distances from upstream pollution sources. To evaluate and validate this assuption, the fate of microbial parameters as they travelled downstream from each feedlot was estimated using two statistical models.

(i) Distance-Decay Model

Based on R^2 (coefficient-of-determination) values and Standard Errors of the predicted equations, the distance-decay model was found to be unsatisfactory for describing the reduction in microbial counts during downstream transport. This was the result of its univariate nature. It appeared, therefore, that other physical and chemical properties (variables) of the receiving waters must be added to the equations to obtain an effective model of the fate of microorganisms.

(ii) Multiple-Regression Model

The multiple-regression equations of this model were found to be the most useful for the prediction of downstream microbial densities. The R^2 (coefficient-of-determination) values indicated that 73% to 99% of the variation in counts could be attributed to the significant independent hydrological, physical and chemical variables in this model. This range is quite acceptable because in a complex natural biological system it is almost impossible to account for 100% of the variation.

The most significant predictor variables included: temperature (TEMP), pH, non-filterable residues (NFR), filterable residues (FR), turbidity (TURB), nitrite + nitrate nitrogen (NO_2+NO_3), specific conductance (SCOND) and distance (DIST). These variables should be emphasized, therefore, and preferably examined in any future monitoring programs and feedlot-impact studies.

(f) The presence and detection, albeit in small concentrations, of both the microbial physical and chemical parameters during all surveys suggest that pollution potential exists, not only under spring and storm-event runoff, but also under dry-weather conditions. Therefore, it is recommended that specific guidelines for livestock manure management and runoff control be developed under all types of hydrological runoff conditions.

(g) The approach taken in this study was found to be suitable and satisfactory according to its design and objectives. For a more comprehensive assessment of the impact of feedlot runoff on receiving waters, however, it is suggested that a detailed study of only ONE feedlot under different seasonal conditions be conducted to emphasize only those selected parameters found to be significant in this study.

7.0 RECOMMENDATIONS

7.1 Waste Management and Runoff Control

Since feedlot runoff contains varying levels and types of microorganisms, nutrients, metals and other pollutants, it could have a significant and measurable impact on the quality of receiving surface waters. These surface waters may be at, or near, the maximum recommended limits for various uses. Even before a study is made of feedlot runoff, non-point sources from adjacent farmlands could have contributed various contaminants to such waters before the feedlot runoff has had a chance to affect a change in the water quality. The results of this study indicated that the effects of runoff were variable and markedly influenced by the feedlot type, size, season and a variety of complex environmental factors. Nevertheless, sound feedlot waste management practices and runoff control measures should be applied to minimize potential adverse impact and to prevent surface-water pollution problems. In this regard, some recommendations are proposed, as follows:

(i) Construct and locate feedlots following the Alberta Agriculture/Environment "Code of Practice" (5) at suitable sites. This will allow the containment of runoff on the owner's property and prevent direct drainage of runoff into receiving surface waters.

(ii) Control runoff by the installation of diversion ditches and berms, which direct the effluent flow into catchbasins. If the receiving land has only minimal slope, another acceptable method is to provide a small contoured berm that will to cause the runoff to spread out over a large area, allowing the crop being grown to utilize the available nutrients.

(iii) Store and stockpile animal wastes and manure in distant upland areas away from surface waters, and in a manner that allows seepage or runoff to be minimized and controlled.

(iv) Apply and spread manure onto the land according to the recommended rates and conditions. If an increased rate is desired, the rate should not exceed the nutrient uptake of the crop to be grown on that land. Also ensure that all manure is cultivated into the soil as soon as possible after spreading to preserve the nutrient value and to reduce the chance of the manure being washed off the land in the event of heavy precipitation. The potential for runoff, of course, will depend on the slope of the land.

(v) Although seasonal variations were observed in levels of microorganisms, nutrients and other pollutants, their presence and detection during all surveys suggested that pollution potential exists not only during spring-runoff and storm-events, but also under dry-weather conditions. Furthermore, while the impact of spring and storm runoffs may be minimal, resulting from large volumes and fast-flowing receiving waters, the intermittent input from low flows (hence low dilution) under dry-weather conditions may cause serious pollution problems, particularly in small receiving waterbodies. Therefore, it is suggested that more attention be given to manure management and runoff control during dry-weather and spring/storm-runoff conditions according to respective specific guidelines.

7.2 Future Feedlot Studies

The results of this study showed that pollution potential existed at all feedlots examined, but the degree of runoff impact was variable and tended to be localized and site-specific. Therefore, data and information should not be applied to other feedlots in general. Nonetheless, this study has generated a few suggestions for future studies. They are:

(i) Design and conduct an extensive study of only ONE suitable feedlot under different seasonal conditions to ensure the collection of sufficient data for all conditions.

(ii) Select and establish more sampling stations at shorter distances downstream of the feedlot, both in the impact and non-impact zones.

(iii) Develop and use statistically acceptable experimental design and protocols for conducting surveys and for performing analytical and data analyses.

(iv) Examine and perform analyses for selected and significant parameters only. Such parameters should include:

- (a) Physical - TEMP, pH, TURB, NFR, FR, TDS and SCOND.
- (b) Hydrological - distance, flow rate, water volume, and rainfall amount.
- (c) Chemical - NO_2+NO_3, TKN, OP, TP, and DOC.
- (d) Microbial - TC, FC, FS and HPC 20°C.

(v) Use a Multiple-Regression (Multivariate) Model (such as the one used in this study) to determine feedlot runoff impact and to predict the nature, fluctuations and fate of downstream transport of microorganisms.

DO NOT USE A DISTANCE-DECAY MODEL as it was found to be inadequate for determining the downstream transport of microbial parameters and to account for the variations in microbial densities.

(vi) Because of the dynamic nature and complexity of the overall feedlot system, it is imperative that any future studies be conducted by a Project Team consisting of a Microbiologist, Chemist, Biometrician and Livestock Waste Management Specialist.

8.0 REFERENCES

1. Anon. 1973. Alberta Livestock Operations Waste Management Survey. Alberta Environment, Edmonton, AB. 69 p.

2. Anon. 1977. Surface Water Quality Objectives. Alberta Environment, Standards and Approvals Division and Pollution Control Division, Water Quality Control Branch, Alberta Environment, Edmonton, AB. 17 p.

3. Anon. 1978. Oldman River Basin Study Phase II, Water Quality. Envirocon Ltd., Calgary, AB. 60 p.

4. Anon. 1981. Methods Manual for Chemical Analysis of Water and Wastes. Alberta Environmental Centre, Vegreville, AB. AECV81-M1.

5. Anon. 1982. Confinement Livestock Facilities Waste Management. Code of Practice. Alberta Environment, Alberta Agriculture, Edmonton, AB. 32 p.

6. Anon. 1983. Guidelines for Canadian Recreational Water Quality. Health and Welfare Canada. Ottawa, ON. 75 p.

7. Anon. 1985. Standard Methods for the Examination of Water and Wastewater, 16th edition. American Public Health Association, American Water Works Association, and Water Pollution Control Federation. Washington, D.C. 1268 p.

8. Anon. 1990. Microbiological Methods Manual. Alberta Environmental Centre, Vegreville, AB. AECV90-M2. 437 p.

9. Barber, E. 1971. Stream Survey, 1970. Alberta Agriculture, Edmonton, AB. 16 p.

10. Bennett, M. R. and D. N. Graveland. 1976. A Study of the Impact of Cattle Feedlots on Soils and Shallow Groundwater. Alberta Environment, Edmonton, AB. 46 p.

11. Box, G. E. P., W. G. Hunter and J. S. Hunter. 1978. Statistics for Experimenters: An Introduction to Design, Data Analysis and Model Building. John Wiley and Sons, Inc. New York, NY.

12. Casbourn, H., G. Likes and P. Richard. 1977. Water Pollution by Feedlots: A Legislative and Institutional Analysis. (Submitted by D. DePage as part of the requirements of Int. D. 369). Edmonton, AB. 38 p.

13. Draper, N. R. and H. Smith. 1981. Applied Regression Analysis, 2nd edition. John Wiley and Sons, Inc. New York, NY.

14. Goatcher, L. J. and A. A. Qureshi. 1981. Bibliography of Cattle Feedlot Manure Management: A Reference Listing of Information on Cattle Feedlot Manure Management and Related Environmental Implications. Alberta Environmental Centre, Vegreville, AB. AECV81-B3. 53 p.

15. Kay, D. and A. McDonald. 1978. Reduction of Coliform Bacteria in Two Upland Reservoirs: The Significance of Distance-Decay Relationships. Water Res. 14:305-318.

16. Kay, D. and A. McDonald. 1983. Predicting Coliform Concentrations in Upland Impoundments: Design and Calibration of a Multivariate Model. Appl. Environ. Microbiol. 46:611-618.

17. Lakshman, G. 1982. Surface Water Pollution from Intensive Livestock Operations. In: Cattle Feedlot Workshop Proceedings, Dec. 8 - 9, 1981; A.A. Qureshi and R.N. Coleman, eds., 1982, Alberta Environmental Centre, Vegreville, AB. AECV82-P1. 149 p.

18. McQuitty, J. B., J. A. Robertson and E. M. Barber. 1971. Feedlot Pollution: A Review. University of Alberta, Dept. Agric. Eng., Res. Bull. No. 71-2. 48 p.

19. Qureshi, A. A. and R. N. Coleman, editors. 1982. Cattle Feedlot Workshop Proceedings. December 8-9, 1981. Alberta Environmental Centre, Vegreville, AB. AECV82-P1. 149 p.

20. Sommerfeldt, T.G. 1972. Environmental Quality of the Oldman River in the Lethbridge-Taber Area. Paper presented at Water Users' Conference, Lethbridge, AB. October 13-14, 15 p.

21. Sommerfeldt, T.G. 1975. Cattle Feedlots -- Case Study in Southern Alberta. Paper presented at Fifth British Columbia Soil Science Workshop, Vancouver, BC. February 26-27, 11p.

22. Sommerfeldt, T.G., V.J. Pittman and R.A. Milne. 1973. Effect of Feedlot Manure on Soil and Water Quality. J. Environ. Qual. 2: 423-427.

23. Taylor, J. E. 1977. Water Quality Study of Willow Creek. Alberta Dept. of Environment, Edmonton, AB. 21 p.